Jonathan J. Gourley
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University of Oklahoma
Norman, Oklahoma, USA

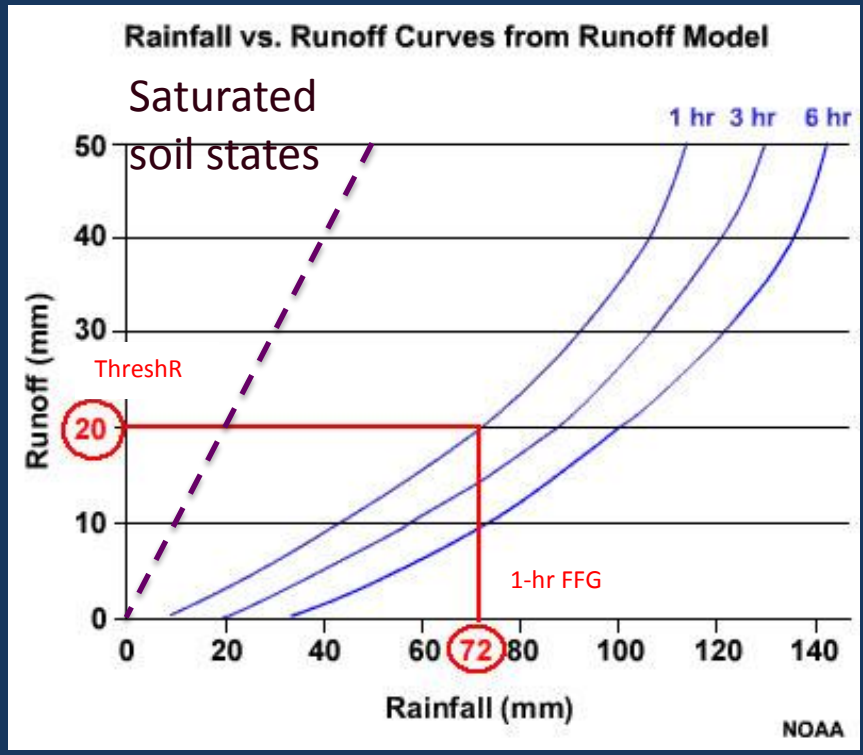
The Past, Present, and Future of Flash Flood Prediction

NWS Flash Flood Guidance System

- Flash Flood Guidance (FFG): average rainfall over a specified area and time duration required to initiate flooding on small streams
- FFG (mm) computed for accumulation periods of 1-, 3-, 6-hr (12, 24 also used)
- If rainfall exceeds FFG, then a forecaster will consider issuing a flash flood warning

How is FFG derived ?

- Lumped SAC-SMA model run under different rainfall scenarios to produce rainfall-runoff curves
- Curves subject to change due to initial soil moisture states, evapotranspiration
- Thresh runoff values (pre-computed) looked up on curves to get FFG



Evaluation of the Operational Tools used for Flash Flood Forecasting in the US

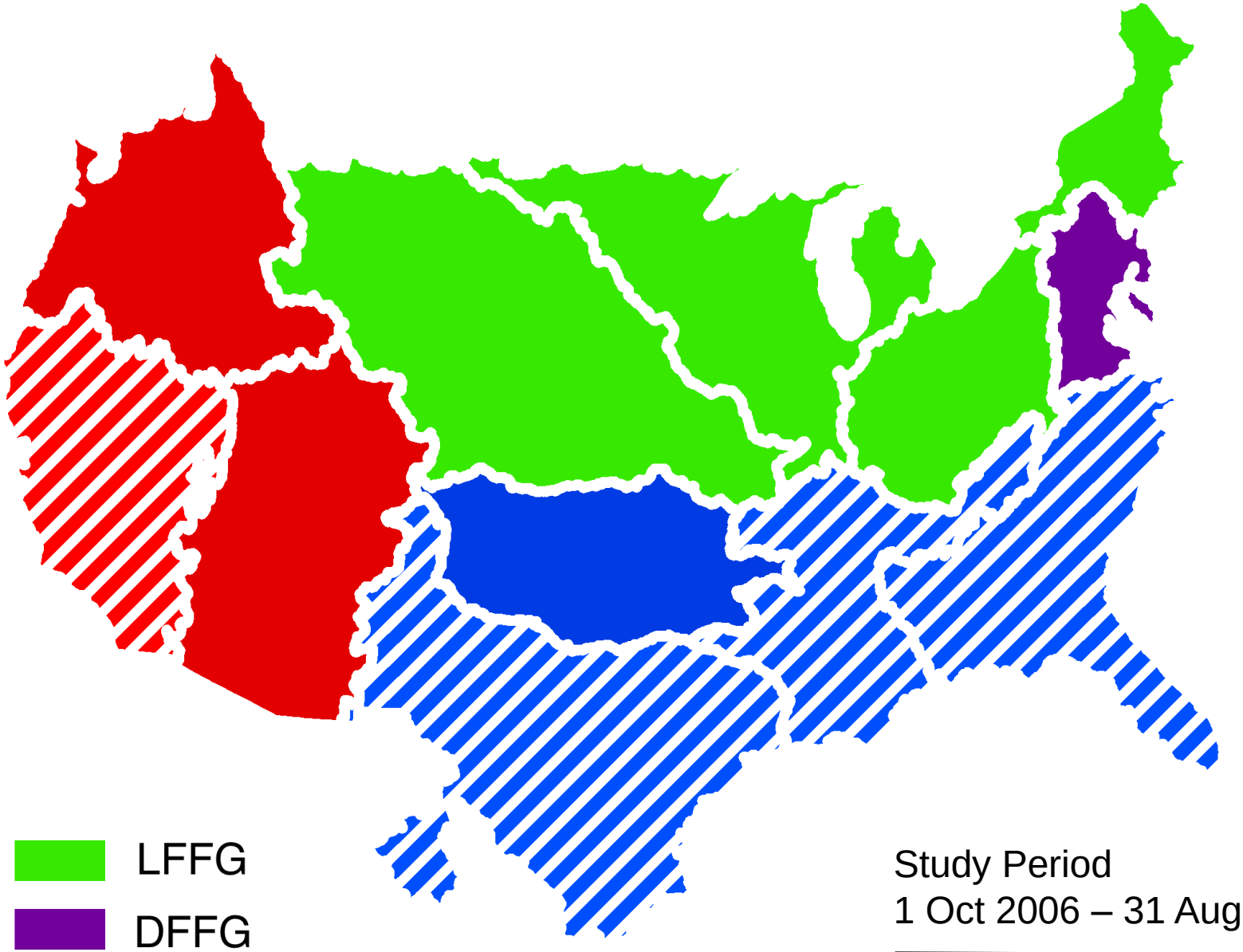
Jess Erlingis
Race Clark

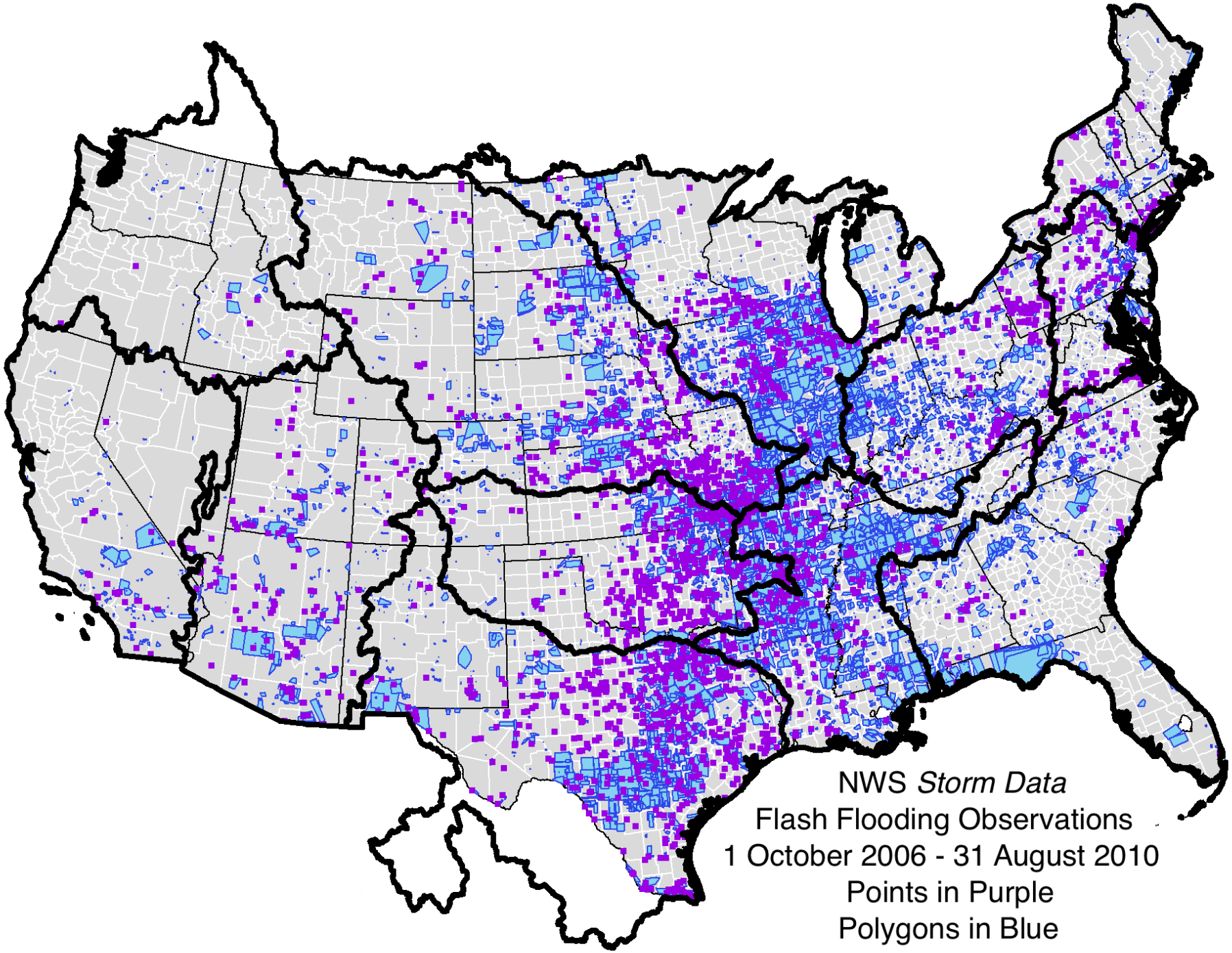
NWS Advanced Hydrologic Prediction Service

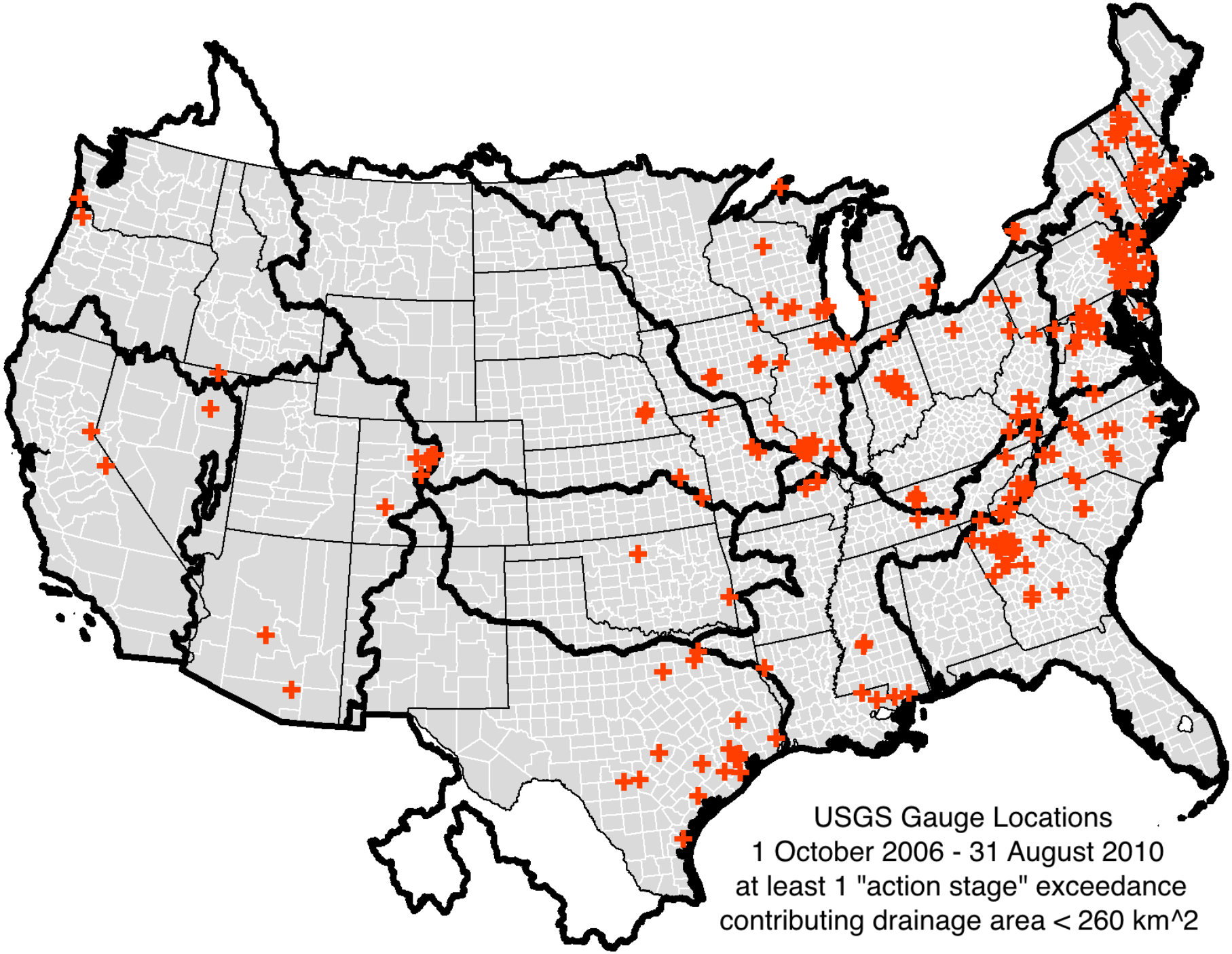
NSF Graduate Research Fellowship

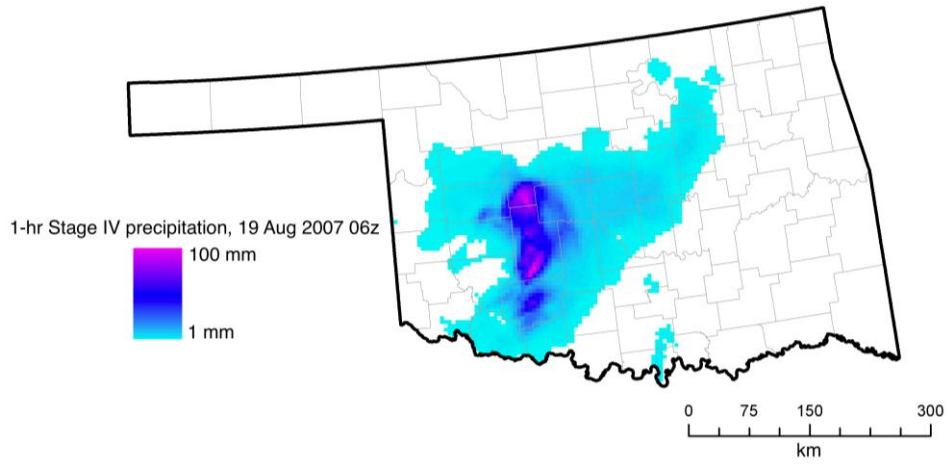
FFG Production

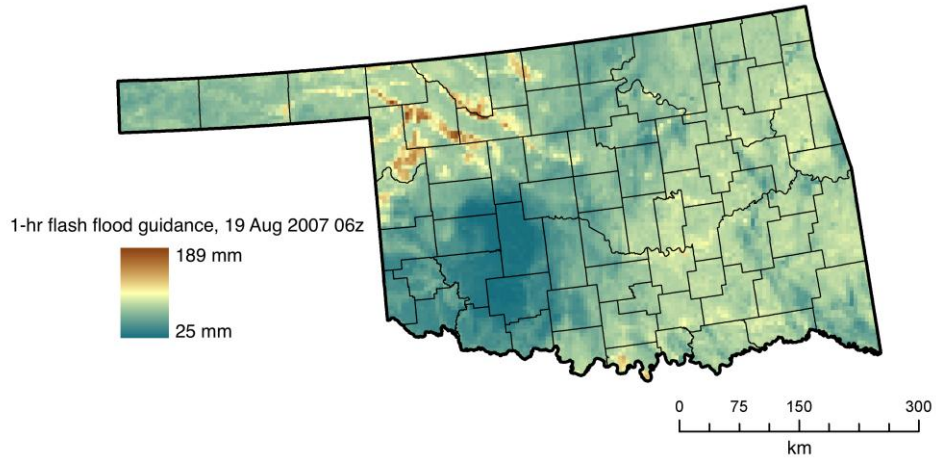
- LFFG – Lumped FFG
  - Lumped-parameter basins (~300 – 3,000 km^2); SAC-SMA model
- GFFG – Gridded FFG
  - high-res product based on NRCS Curve Number method
- DFFG – Distributed FFG
  - Continuous-API (Antecedent Precipitation Index)
- FFPI – Flash Flood Potential Index
  - Quasi-static; geographical characteristics (slope, land cover, wildfire, soil type, …)

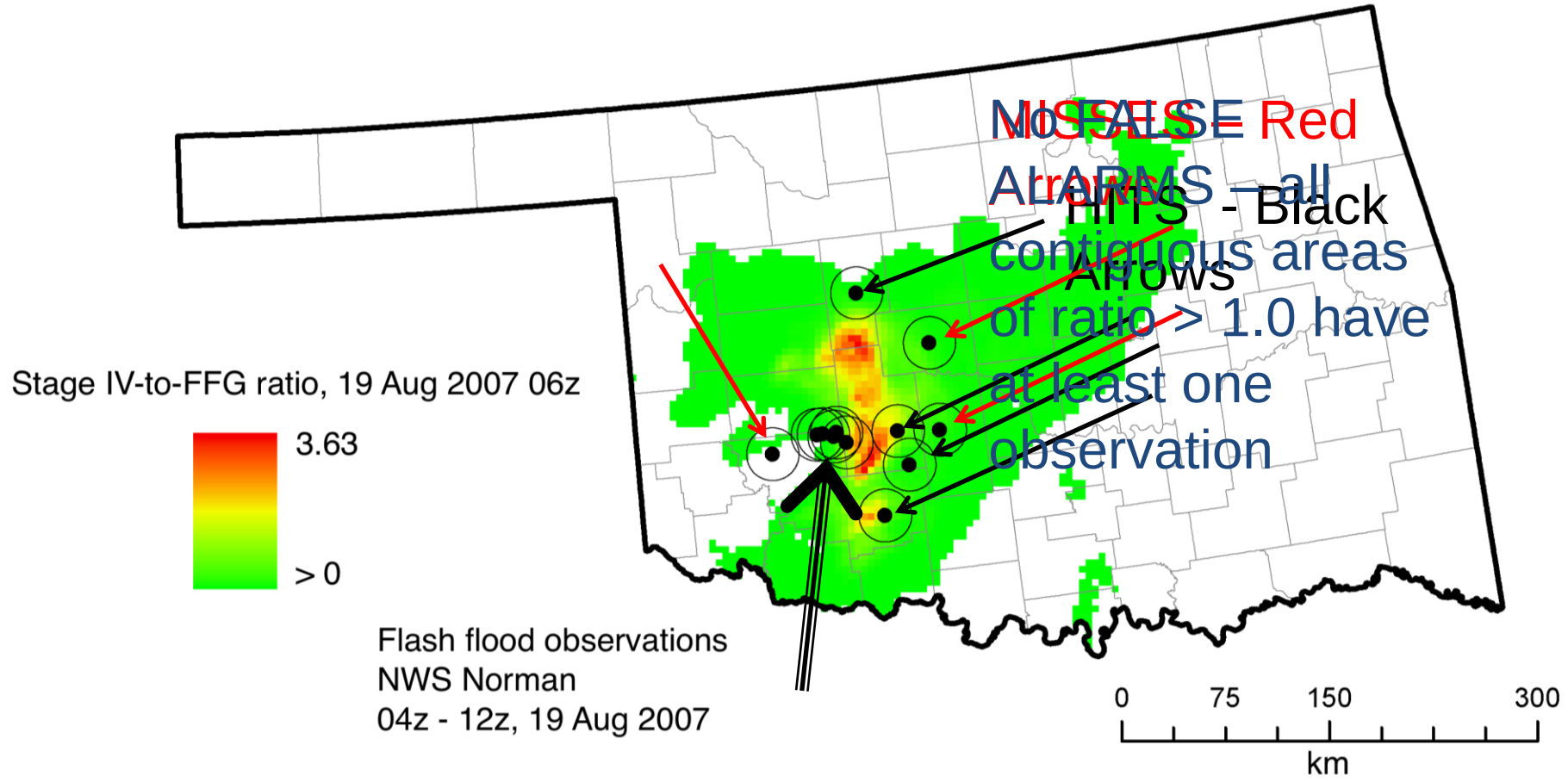

LFFG
DFFG
GFFG
FFPI
LFFG, then GFFG
LFFG, then FFPI
Study Period
1 Oct 2006 – 31 Aug 2010
Changes in FFG generation method occurred in late 2007 or early 2008


NWS *Storm Data*
Flash Flooding Observations
1 October 2006 - 31 August 2010
Points in Purple
Polygons in Blue


USGS Gauge Locations
1 October 2006 - 31 August 2010
at least 1 "action stage" exceedance
contributing drainage area < 260 km^2

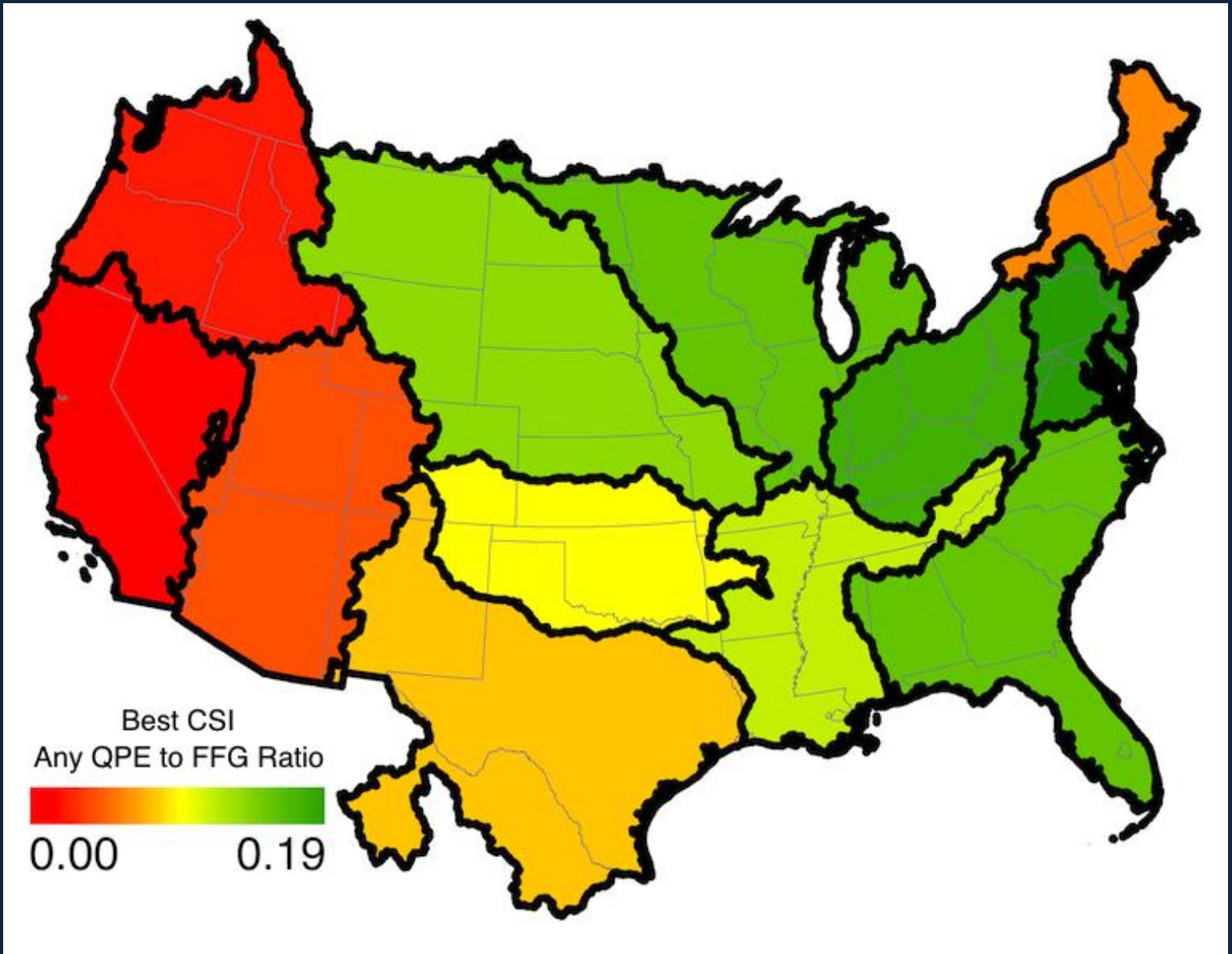




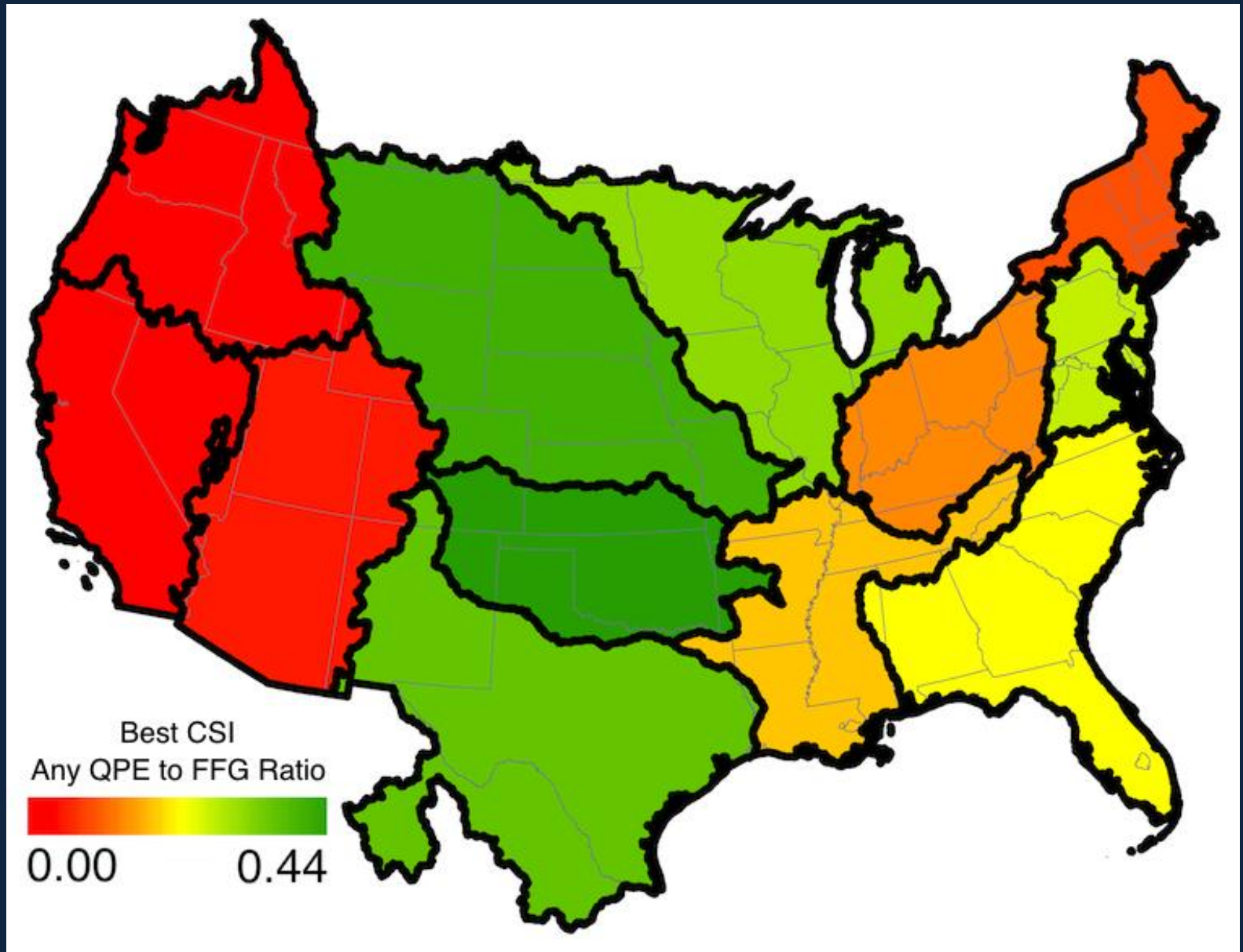


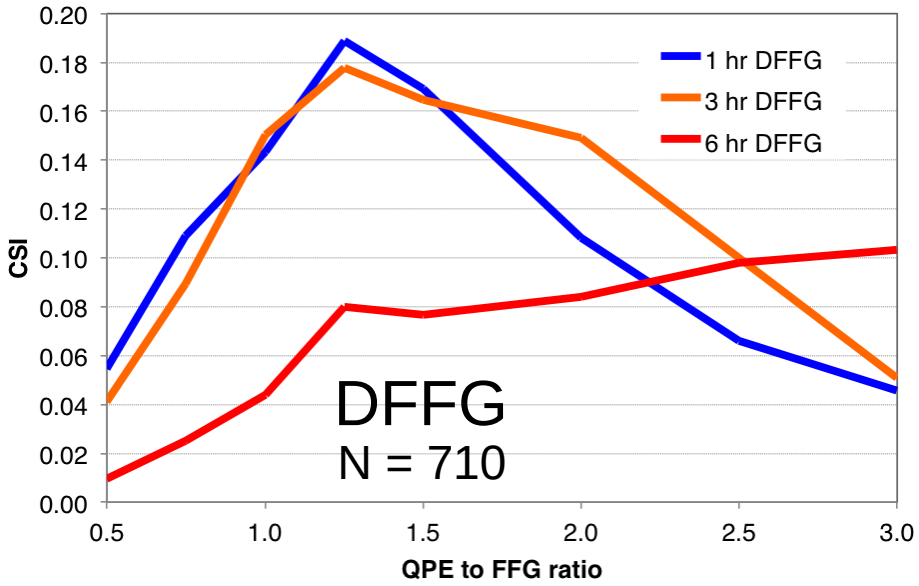
MOSAIC – Red
ARAMS – all
HFTS - Black
Arrows
contiguous areas
of ratio > 1.0 have
at least one
observation

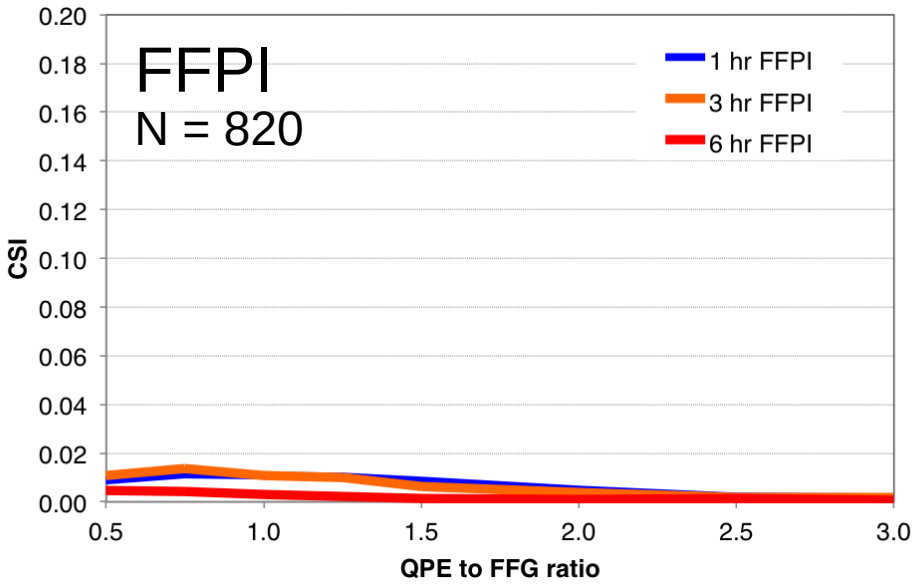
Results – NWS *Storm Data* Analysis

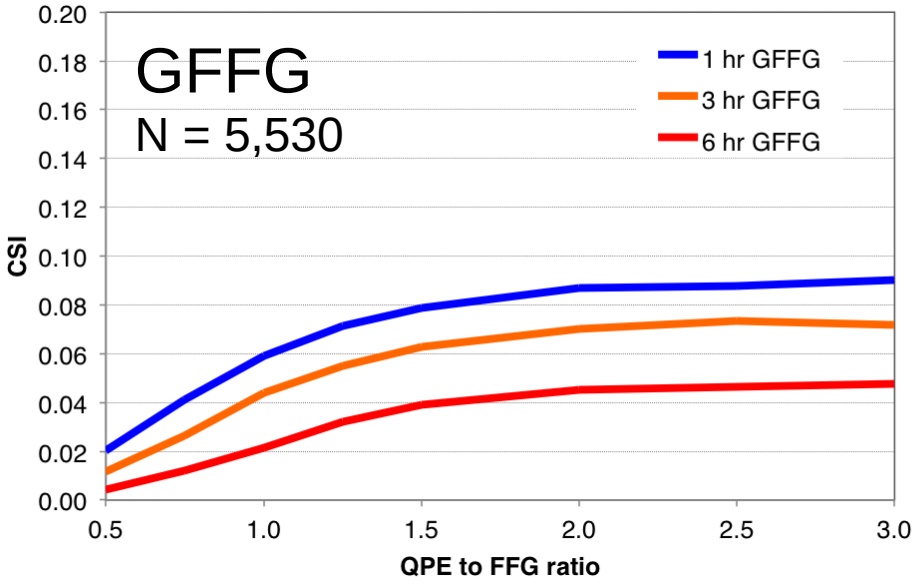


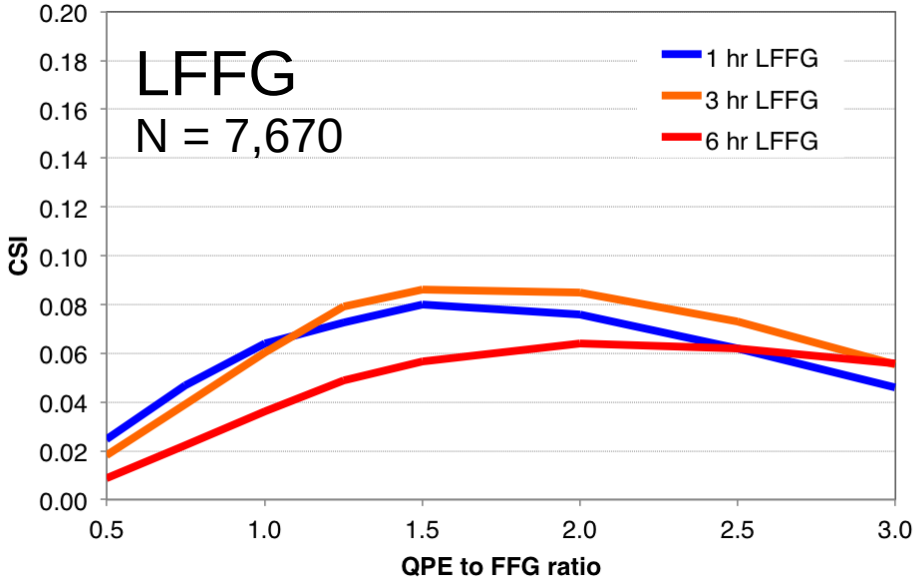
Results – USGS Stage Height Analysis




DFFG
N = 710
1 hr DFFG
3 hr DFFG
6 hr DFFG
CSI
QPE to FFG ratio


FFPI
N = 820
1 hr FFPI
3 hr FFPI
6 hr FFPI
CSI
QPE to FFG ratio


GFFG
N = 5,530
1 hr GFFG
3 hr GFFG
6 hr GFFG
CSI
QPE to FFG ratio


LFFG
N = 7,670
1 hr LFFG
3 hr LFFG
6 hr LFFG
CSI
QPE to FFG ratio

Conclusions/Recommendations

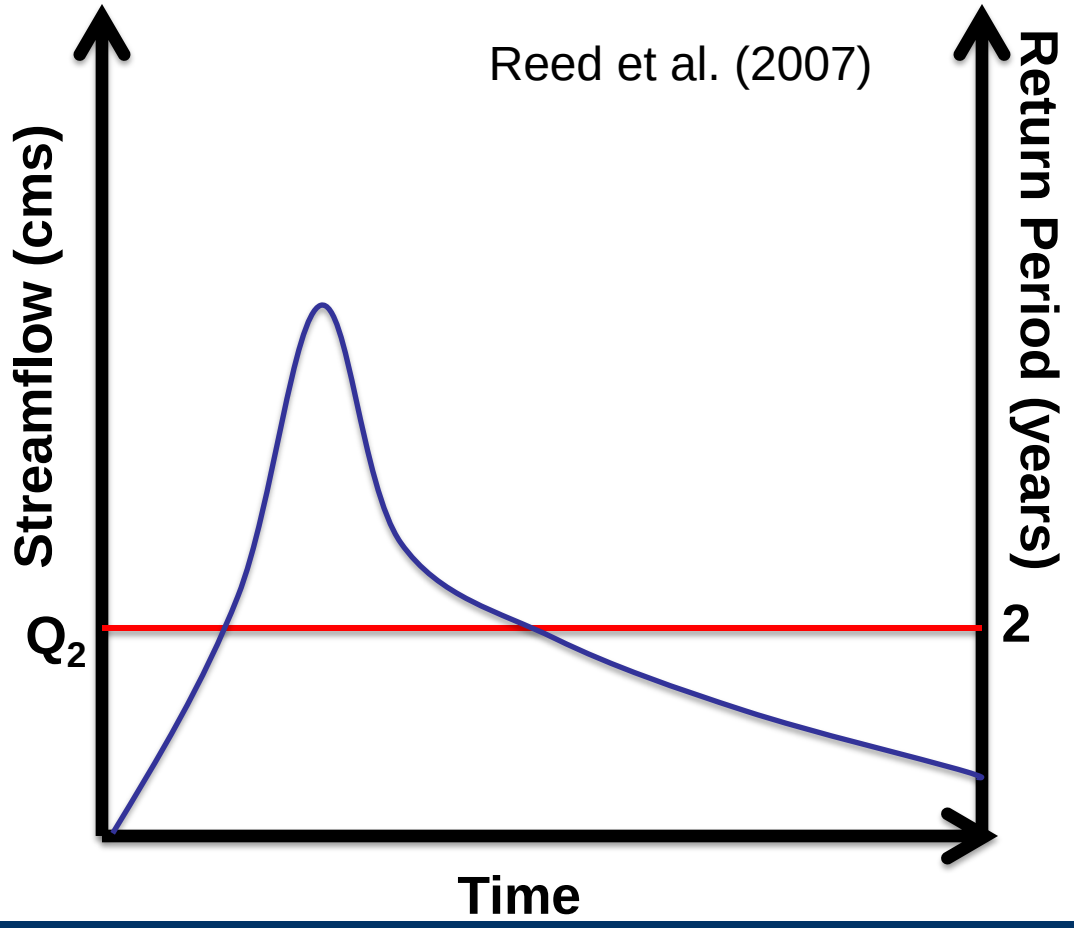
- All methods of FFG in all regions have low CSI (high false alarms; low probability of detection)
  - CSI = 0.19 over Middle Atlantic RFC using 1-hr DFFG & 1.25 QPE-to-FFG ratio
  - This value should be considered as the benchmark skill for future developments
- Both evaluations indicate the worst performance was in CNRFC, CBRFC, NWRFC, and NERFC
- NWS *Storm Data* has large sample sizes, so we use it for intercomparison
  - DFFG is best method
  - LFFG and GFFG have similar skill but GFFG has better resolution
  - FFPI has lowest skill and should be used sparingly
- National system w/consistent skill desirable; but include ability to include local modifications

http://www.nssl.noaa.gov/projects/flash

Threshold frequency method for flash flood prediction

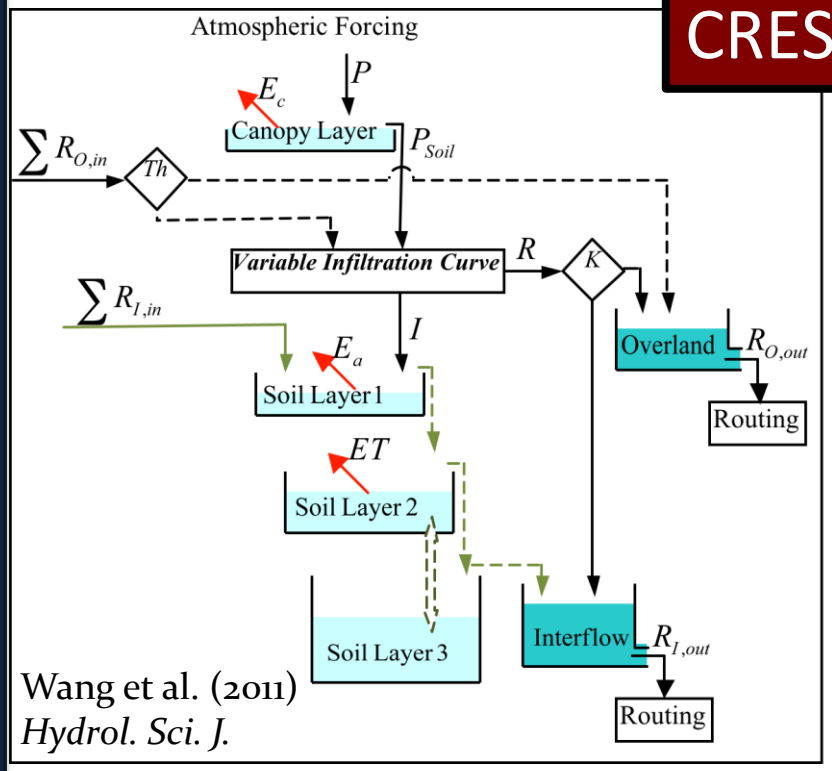
1. Take longest available gridded rainfall record
2. Simulate flow with hydrologic model for period of rainfall recording annual maximum flows @ each grid cell
3. Compute Log-Pearson III distribution from annual maximum sim flows (gives mean, standard deviation and skew parameters)
4. From this distribution estimate we can estimate return period for any discharge value at every grid point

Inherent bias correction for inputs+model



Ensemble Framework For Flash Flood Forecasting (EF5) supports 2 distributed models

CREST



Wang et al. (2011)
Hydrol. Sci. J.

- Concepts from Xinanjiang model
- Runs operationally over globe at OU and NASA
- Has a priori parameters
- 1-km/5-min resolution

HL-RDHM

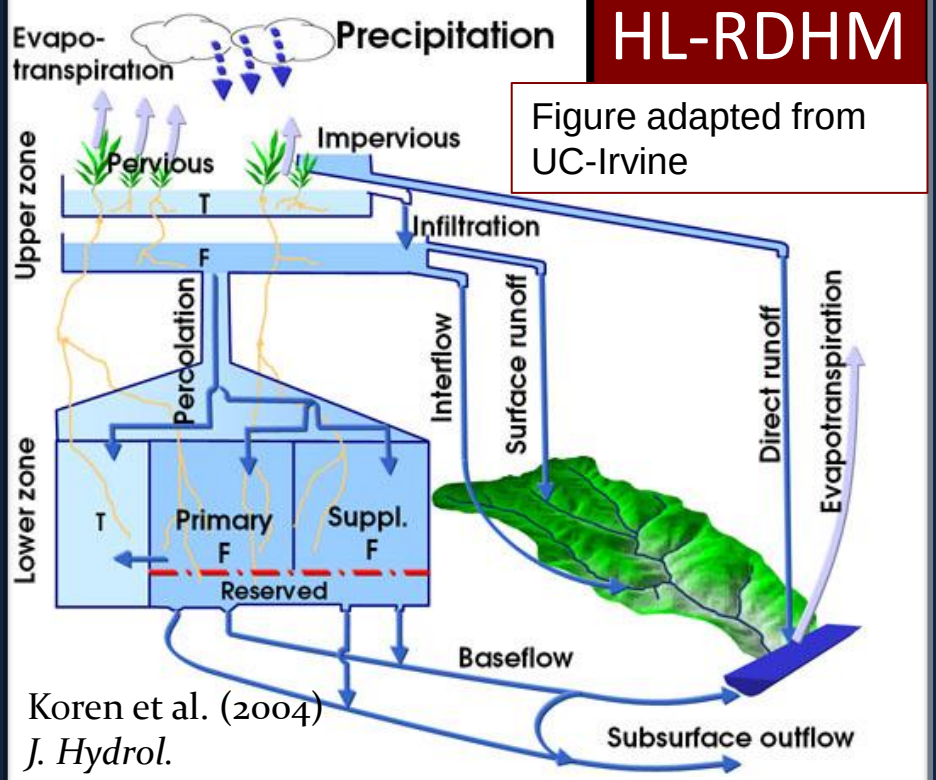


Figure adapted from UC-Irvine

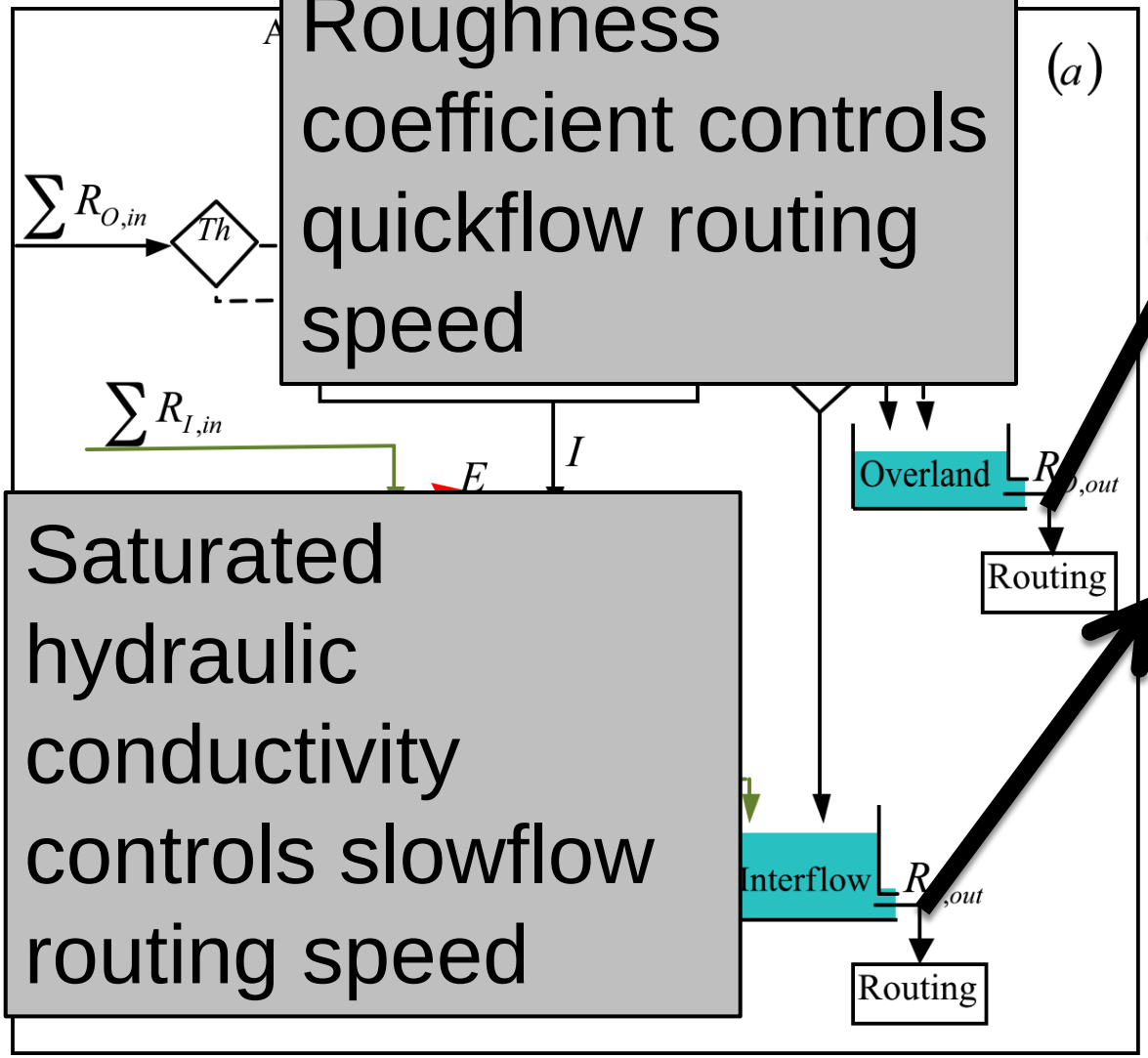
Koren et al. (2004)
J. Hydrol.

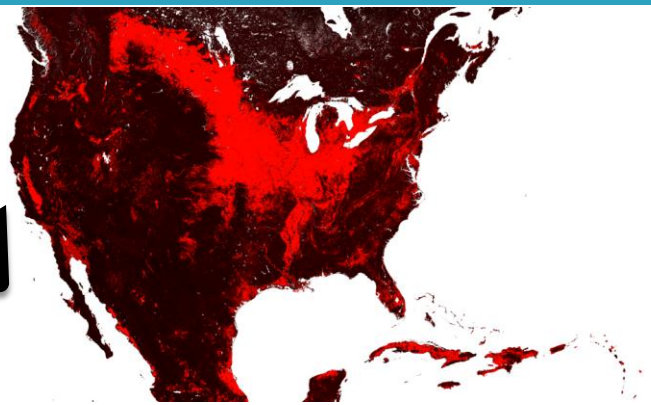
- Concepts from SAC-SMA model
- Runs operationally in US NWS
- Has a priori parameters
- 4-km/1-hr resolution

CREST – a priori parameters

Roughness coefficient controls quickflow routing speed

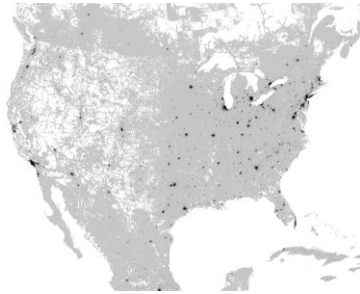
Saturated hydraulic conductivity controls slowflow routing speed





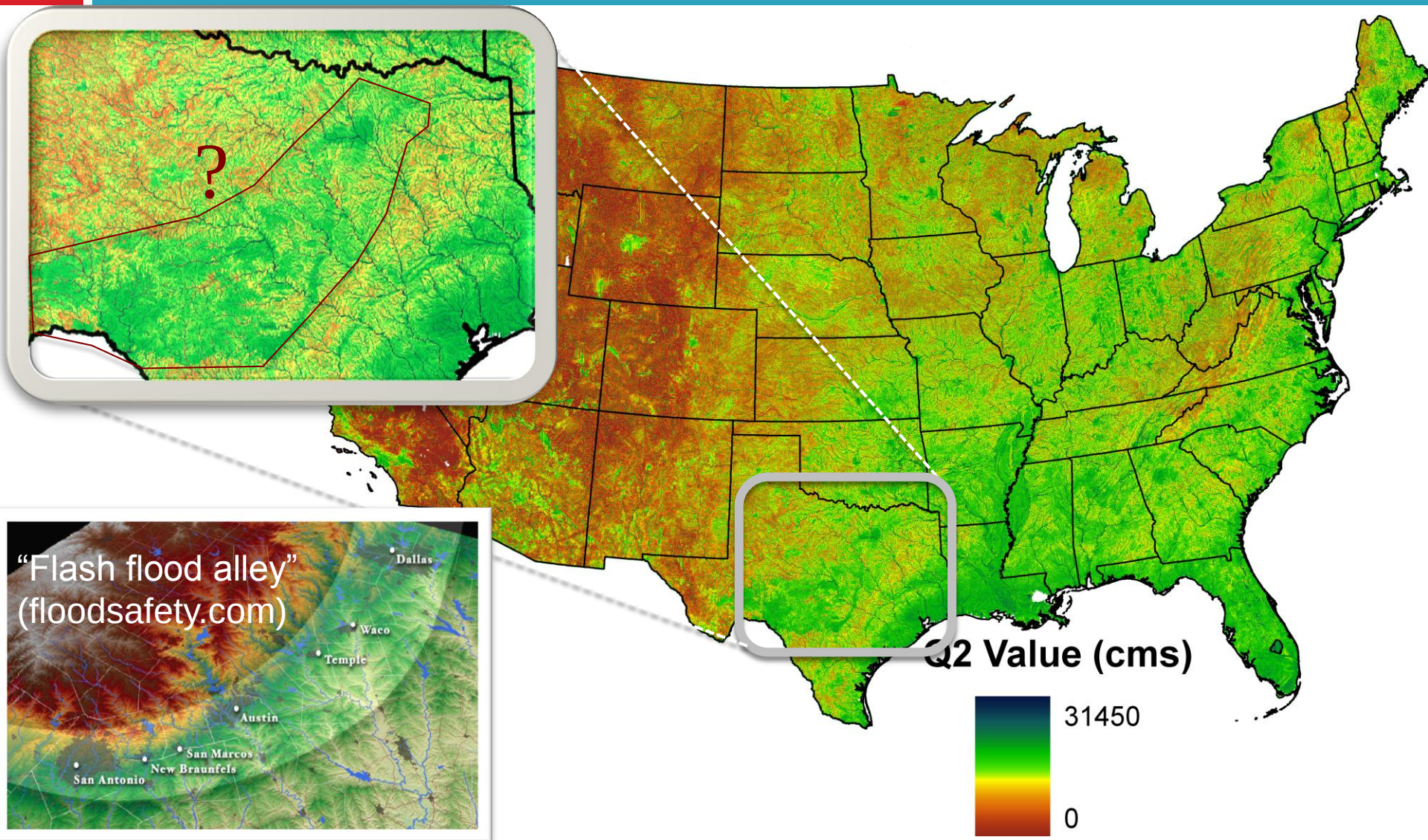
1/(Manning N)

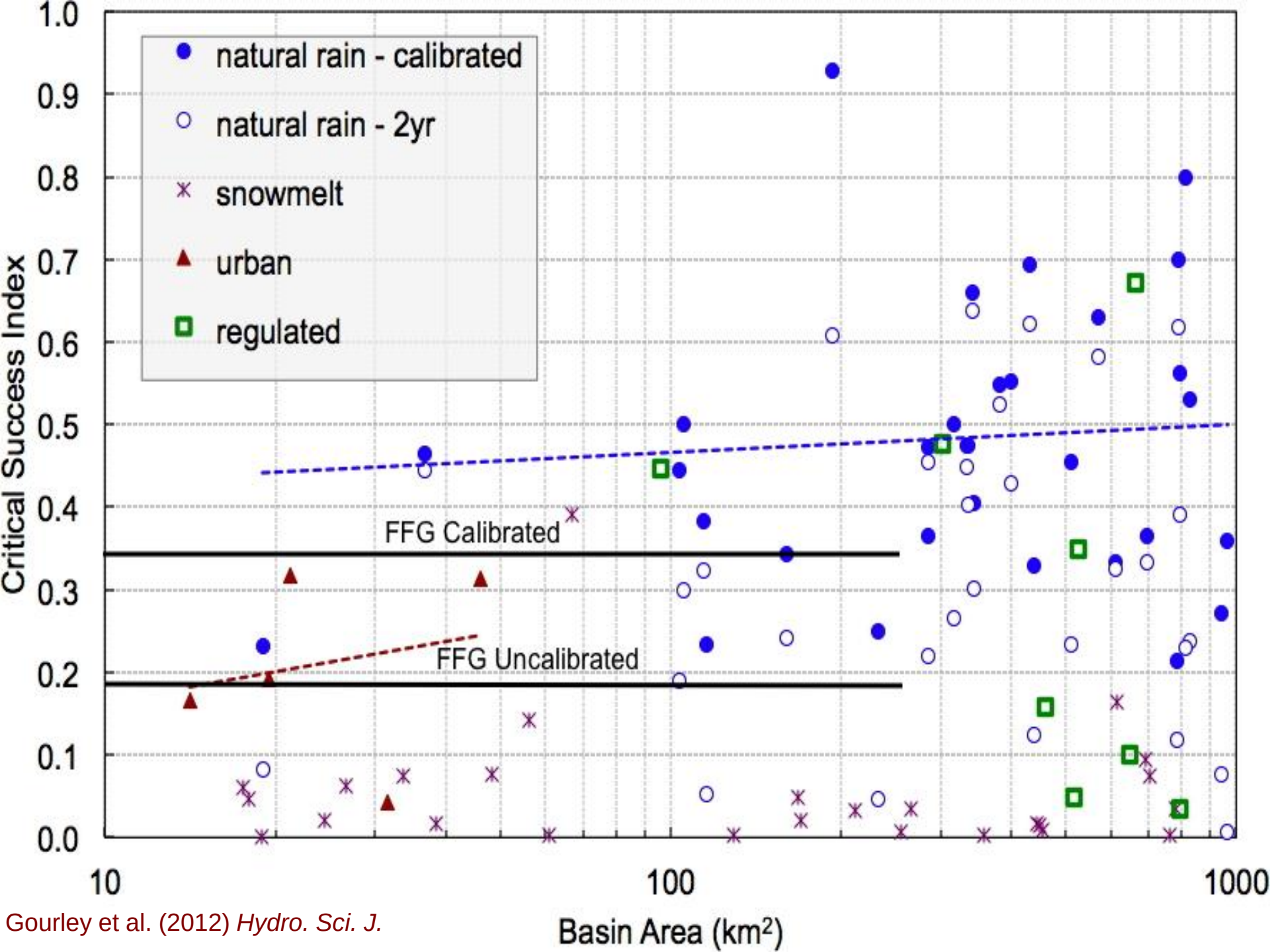
Ksat



% Impervious Area

2-yr return period simulated flows from NEXRAD archive (2002-2010)



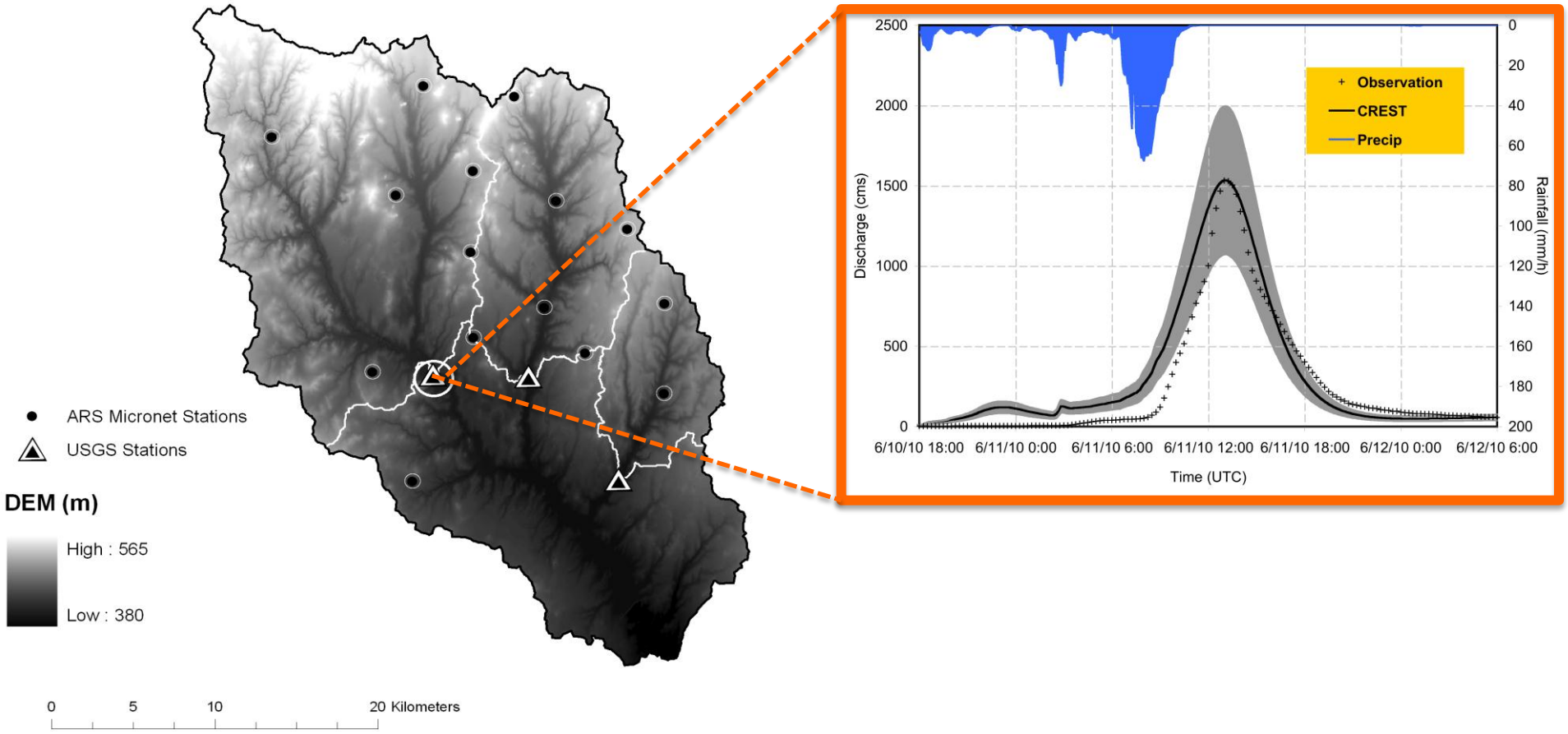


Gourley et al. (2012) *Hydro. Sci. J.*

FLASH: Flooded Locations and Simulated Hydrographs

A demonstration system for real-time flash flood prediction

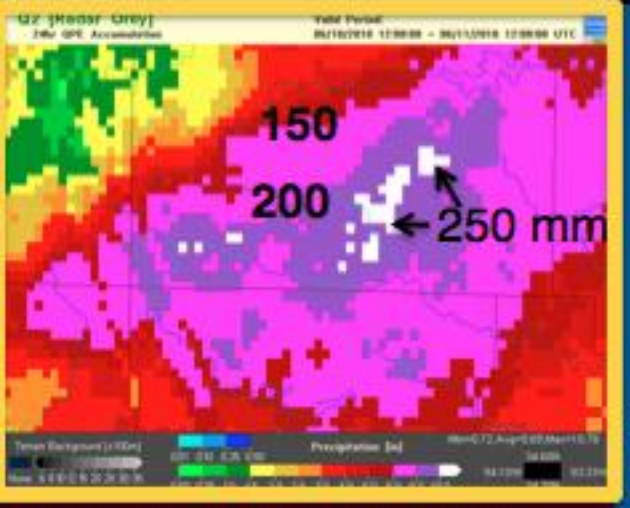
The 1D (traditional) way of doing hydrology



National Mosaic and Multi-Sensor QPE (NMQ) Flooded Locations And Simulated Hydrographs (FLASH)

- A CONUS-wide flash-flood forecasting demonstration system

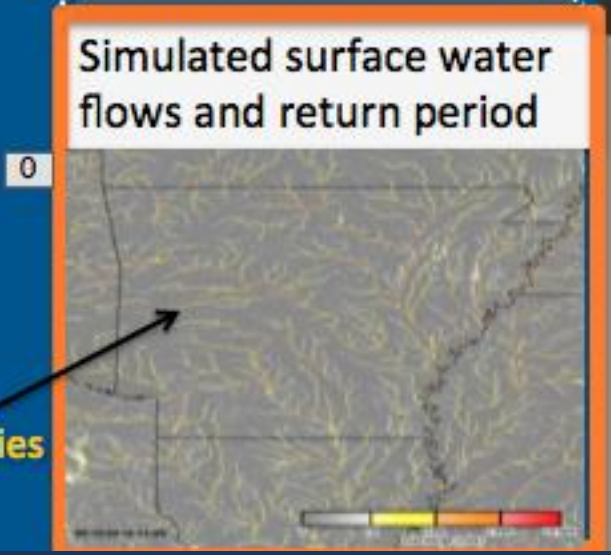
NMQ/Q2 Rainfall Observations
-1km²/5 min
Stormscale Rainfall Forecasts



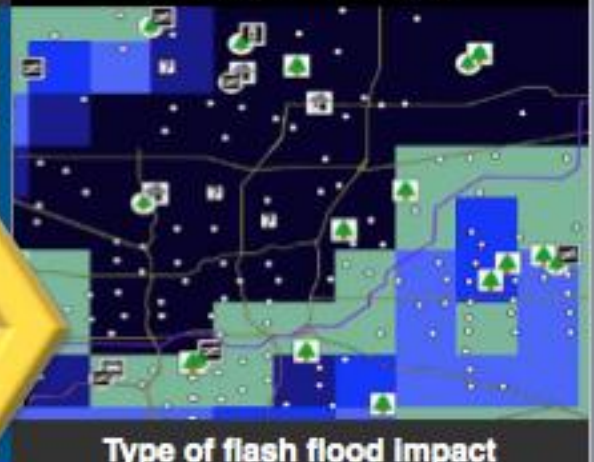
10-11 June 2010, Albert Pike Rec Area, Arkansas

CREST Stormscale Distributed Hydrologic Model
-1km²/5 min

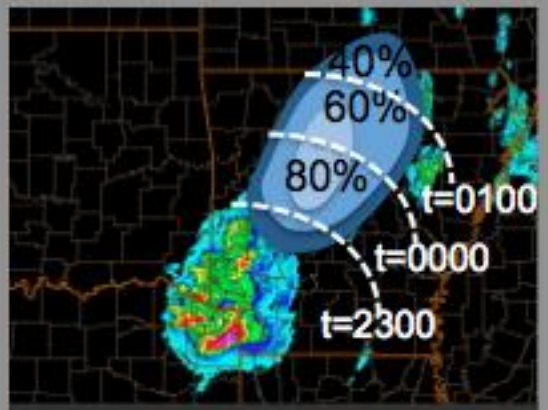
20 fatalities



Probabilistic Forecast Products on the Flash Flood Impacts



Type of flash flood impact according to SHAVE database



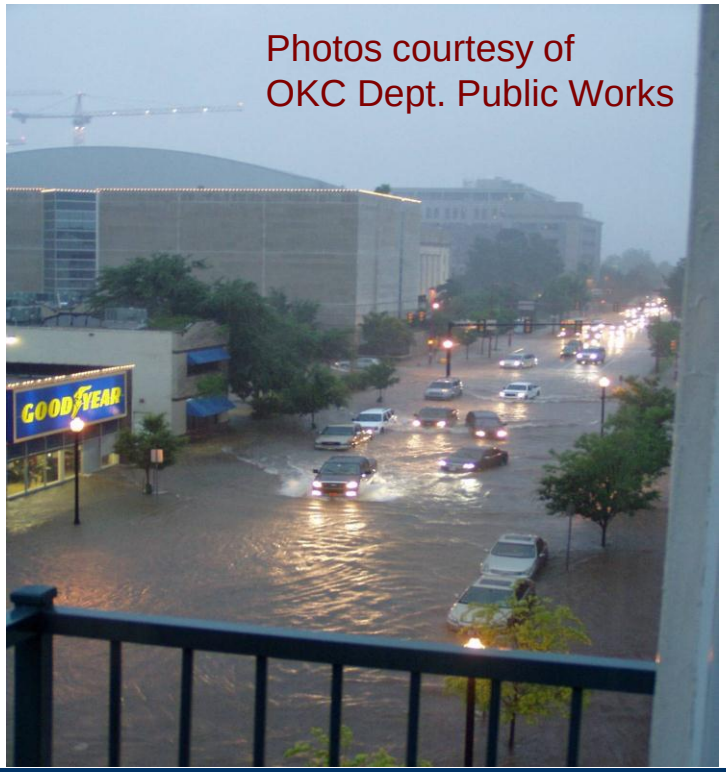
Probability of *life-threatening* flash flood

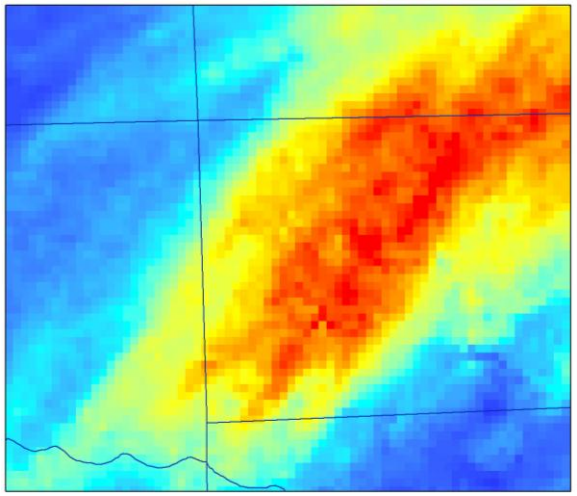
Oklahoma City Flash Flood

Morning of June 14th, 2010

12” of rain in < 6 hours**!**

Lots of flooding & property damage, thankfully no loss of life





Gauges vs QPE

24hr QPE: Q2 [Radar Only]

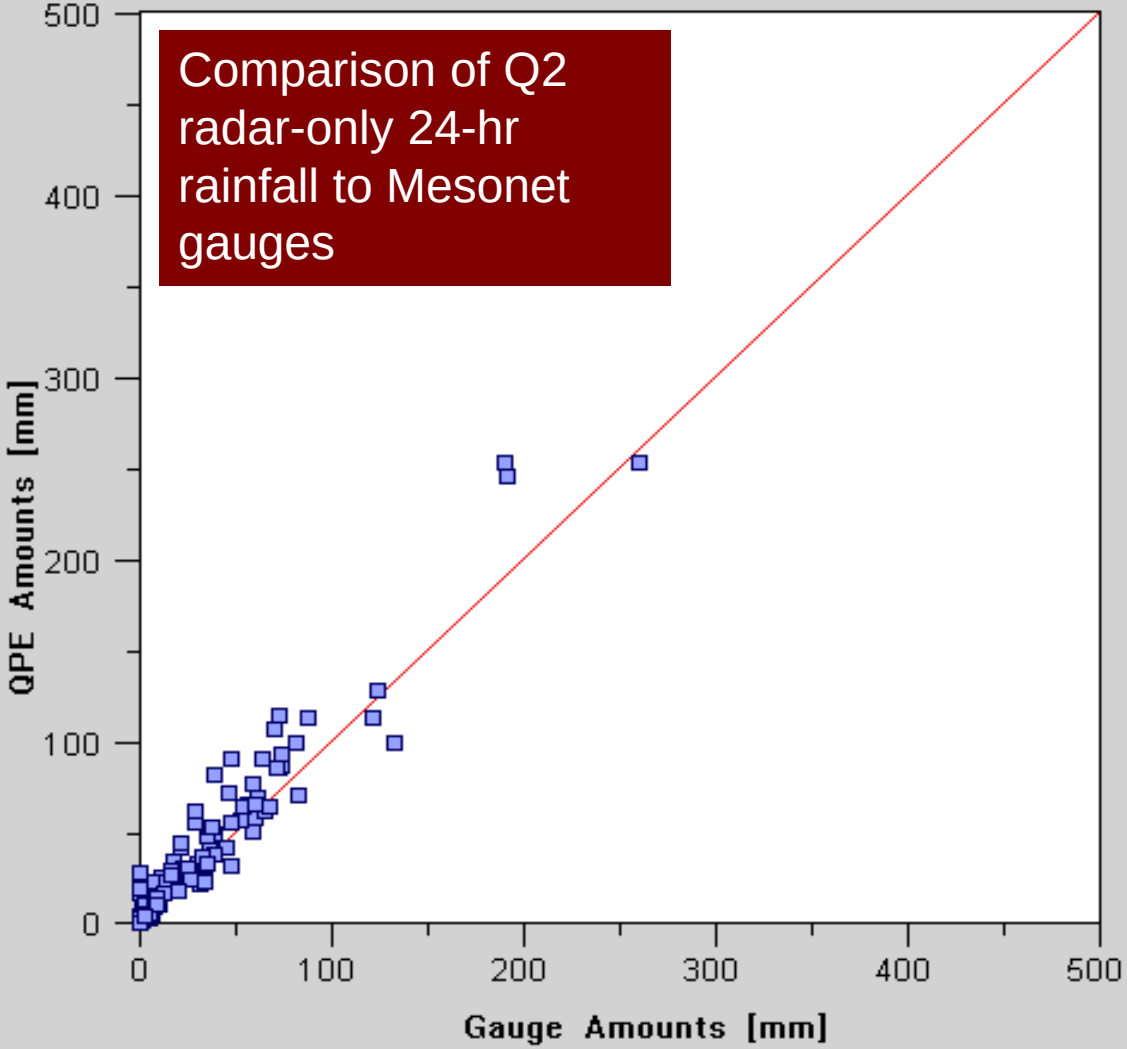
Valid Period: 06/13/2010 20:00 - 06/14/2010 20:00 UTC

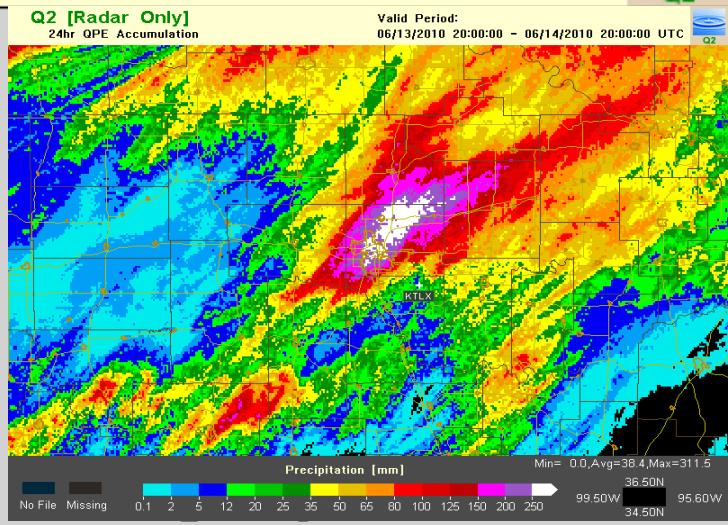
Gauge Groups: OCS

Q2

Scatter Plot:

		Gauge	QPE [mm]
Gauges In Region:	116	Max:	259.59	252.30
Total With QPE:	116	Avg:	30.12	36.51
		Min:	0.00	0.00





Yes/No Threshold: None

Predicted \ Actual	N	Y
Y	0	116
N	0	0

Stats:

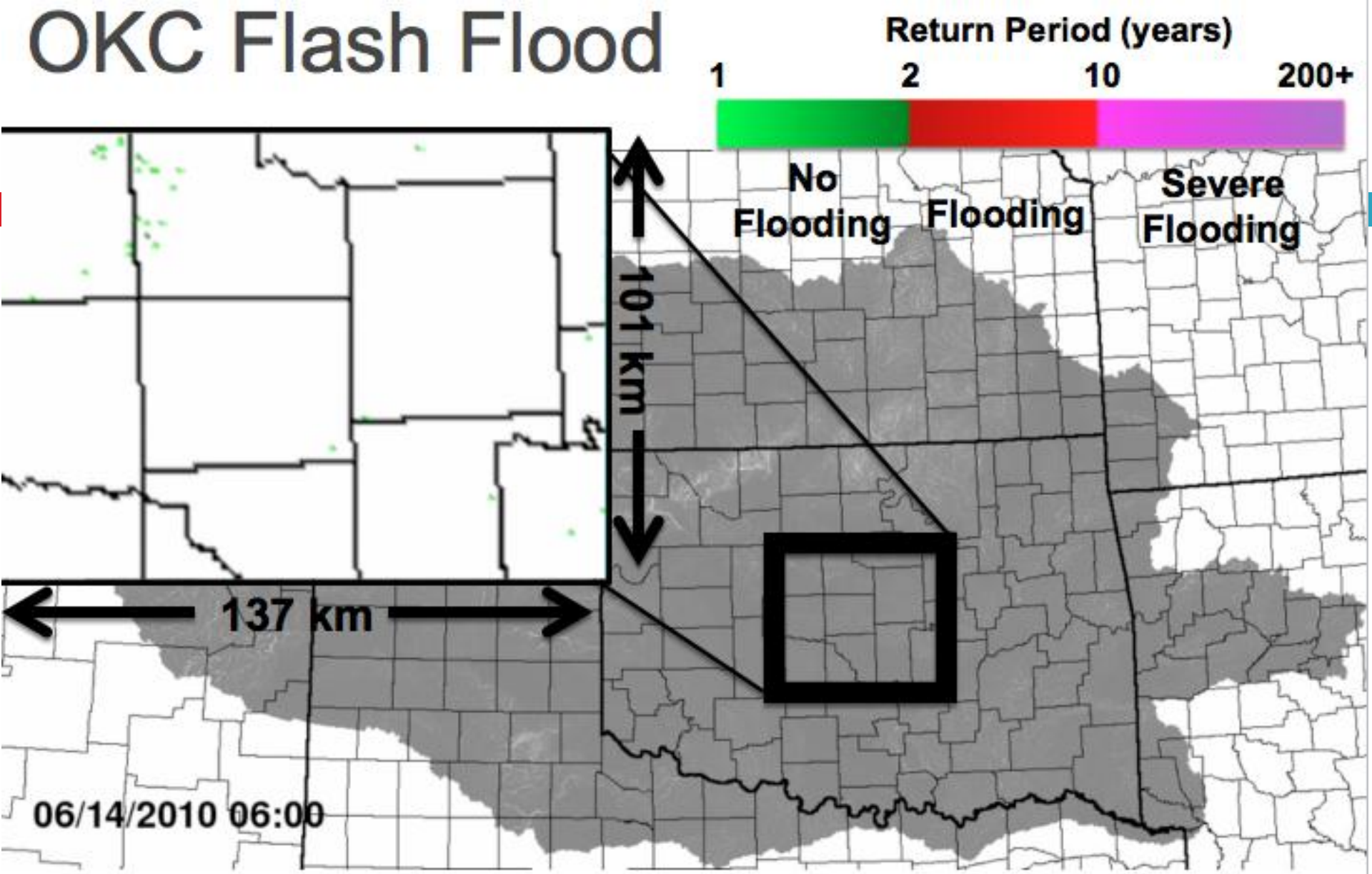
	[Y/Y]	[Y/Y+Y/N+N/Y]
Total Bias:	1.21	1.21
Corr Coeff:	0.96	0.96
RMSE [mm]:	14.80	14.80

Region:

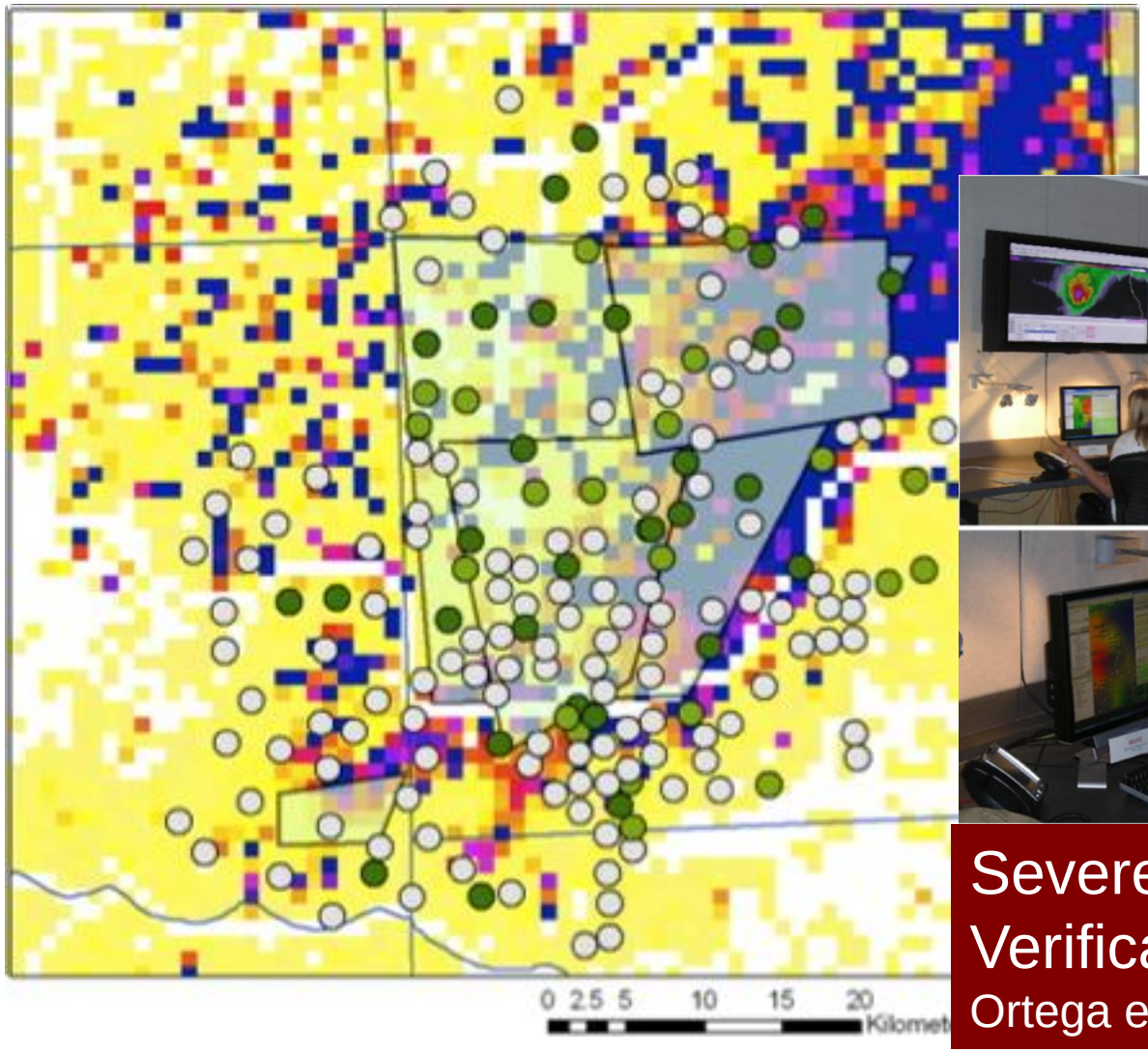
40.00N
106.00W 90.31W
32.00N

Mask: none

Verif Mode: 1pt Accum>=0%


OKC Flash Flood
Return Period (years)
1
2
10
200+
No Flooding
Flooding
Severe Flooding
101 km
137 km
06/14/2010 06:00

Evaluation of Flash Flood Simulations



SHAVE Reports

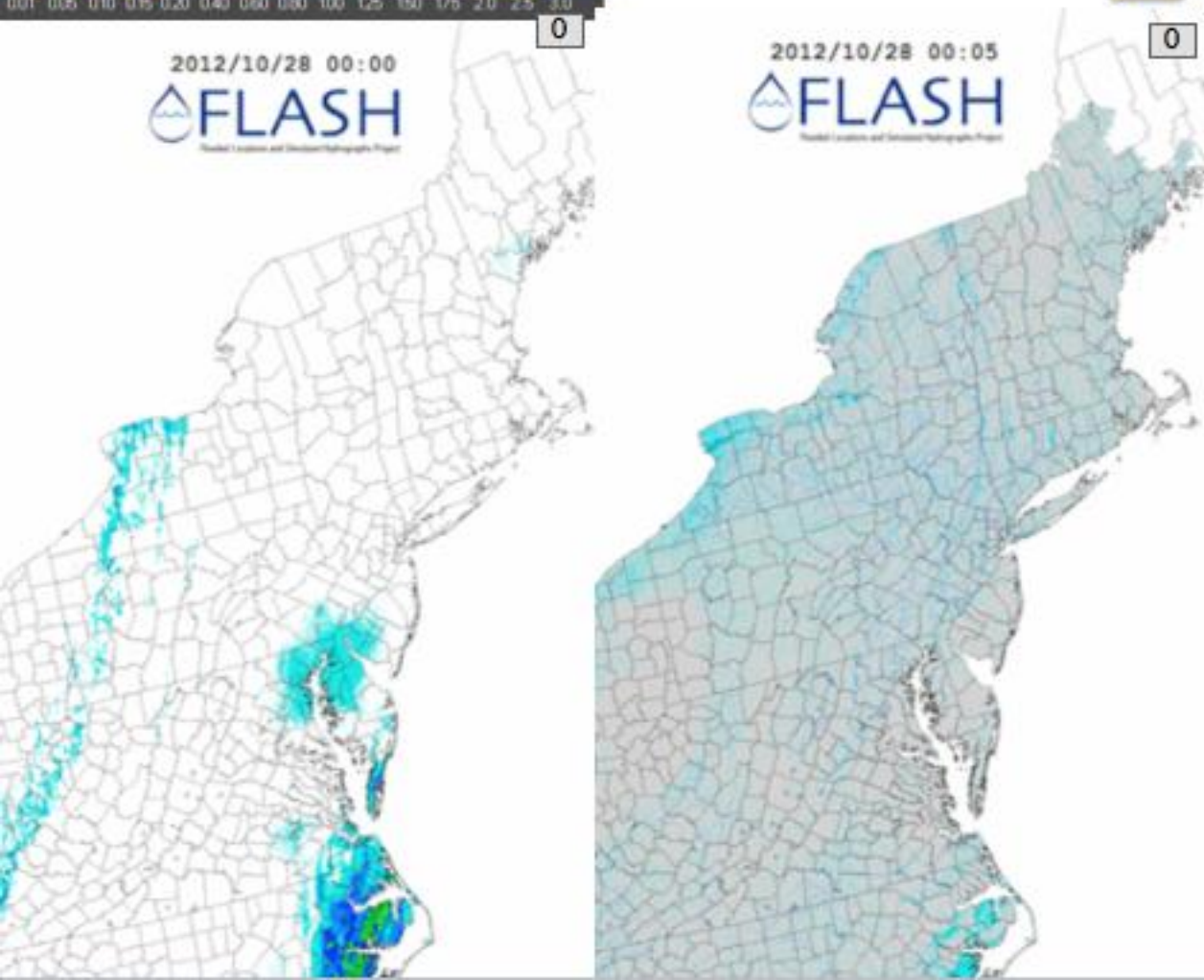
Severe Hazards Analysis and Verification Experiment

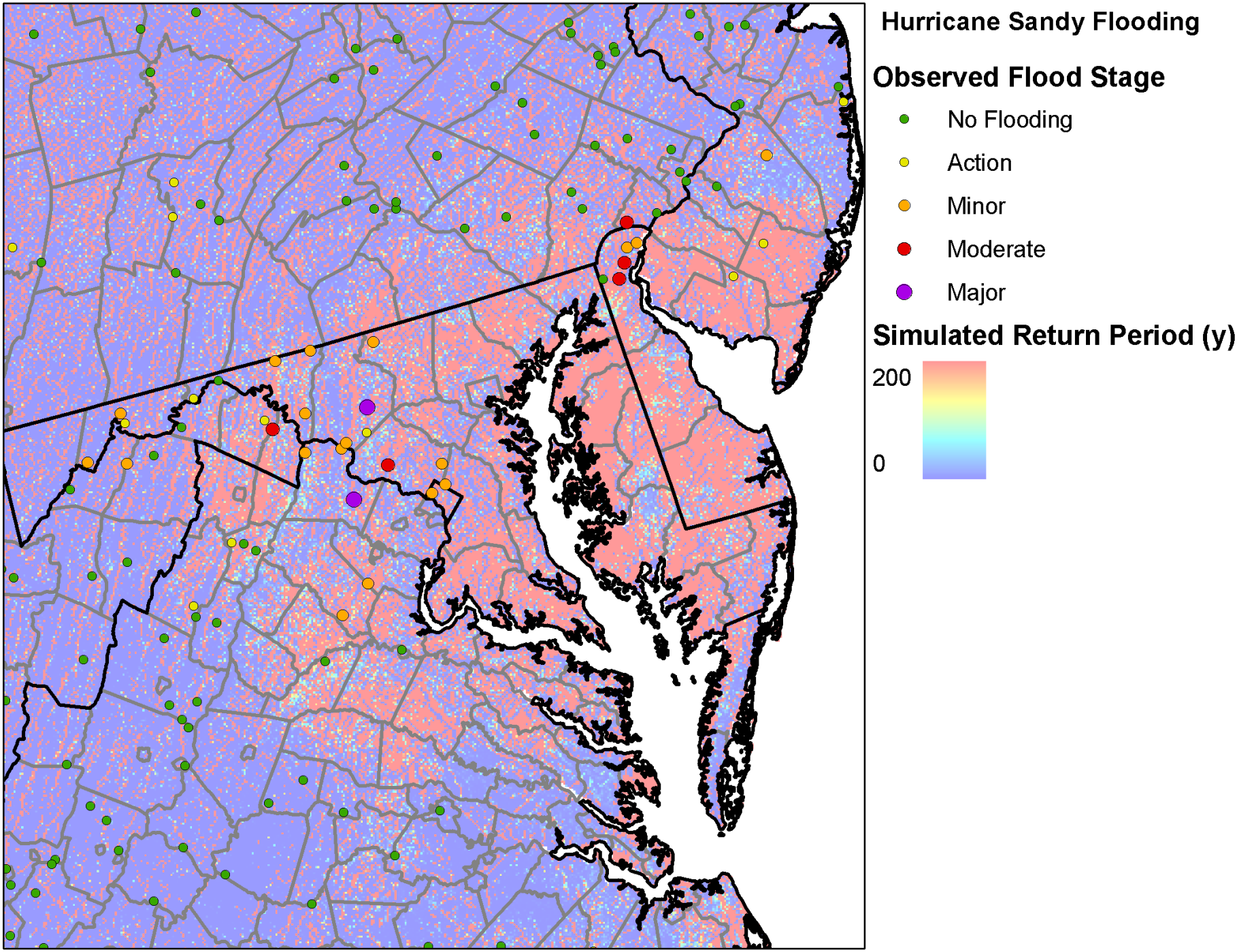
Ortega et al., BAMS (2009)

Rainfall from NMQ/ Q2 Radar-Only Product (5 min/1 km)

Streamflow from CREST Distributed Hydrologic Model (5 min/1 km)

Frequency estimates based on 10-yr StageIV reanalysis

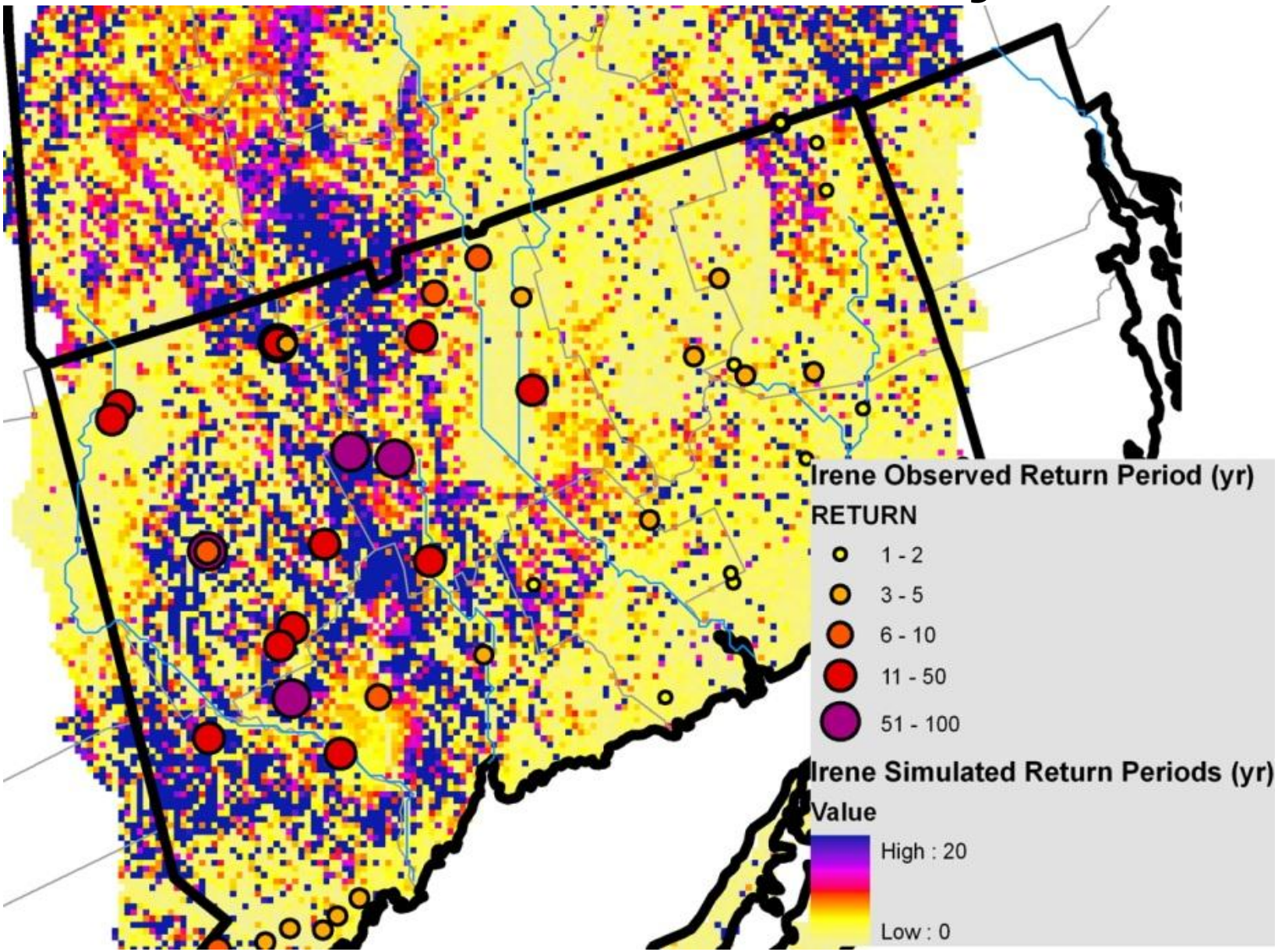



Hurricane Sandy Flooding
Observed Flood Stage
No Flooding
Action
Minor
Moderate
Major
Simulated Return Period (y)
200
0

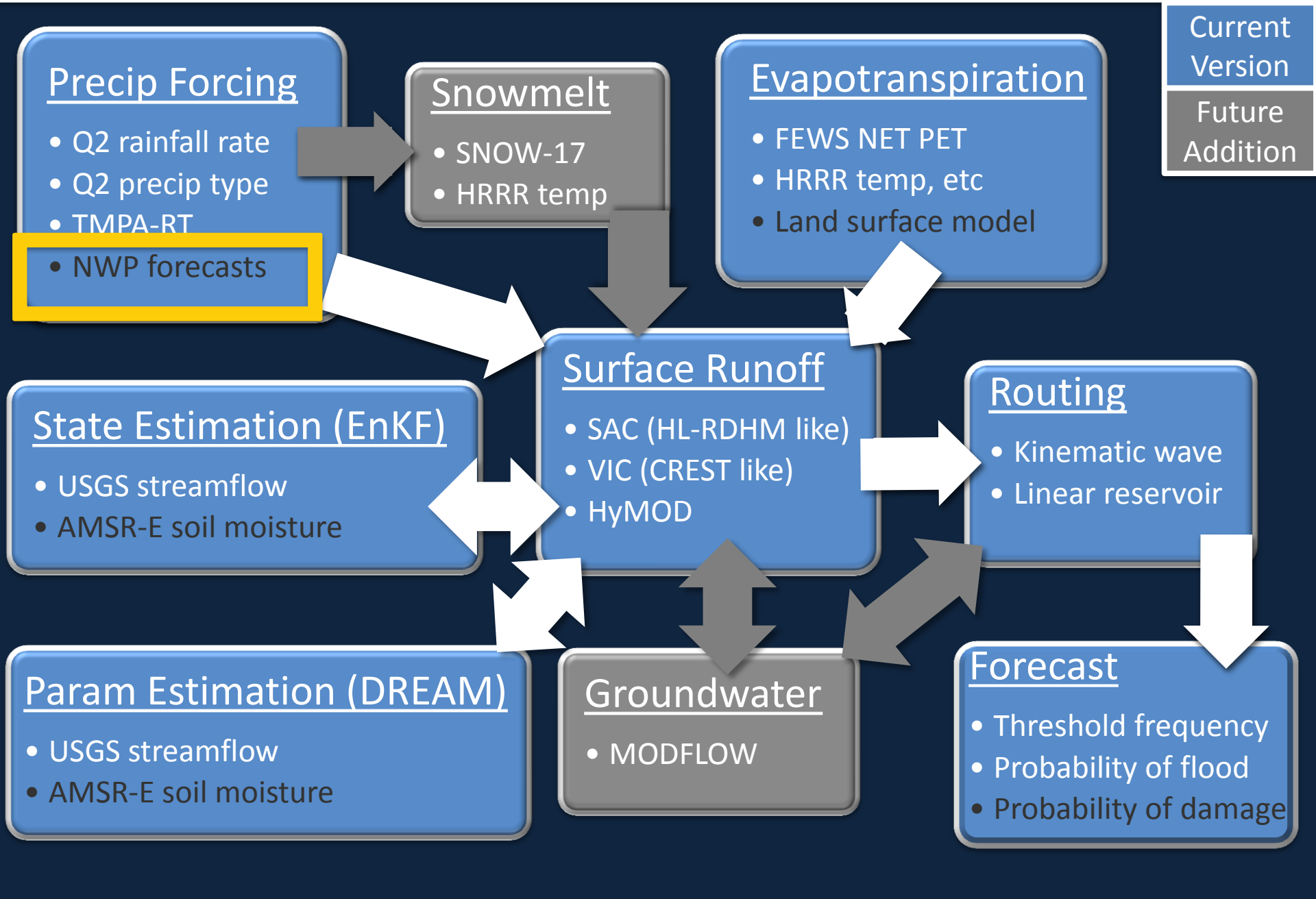
Hurricane Irene

- **Q2 Radar Only QPE**
- StageIV reanalysis from 2002-2011 to produce estimated simulation return periods

Distributed Flood Severity Index



Ensemble Framework For Flash Flood Forecasting (EF5)

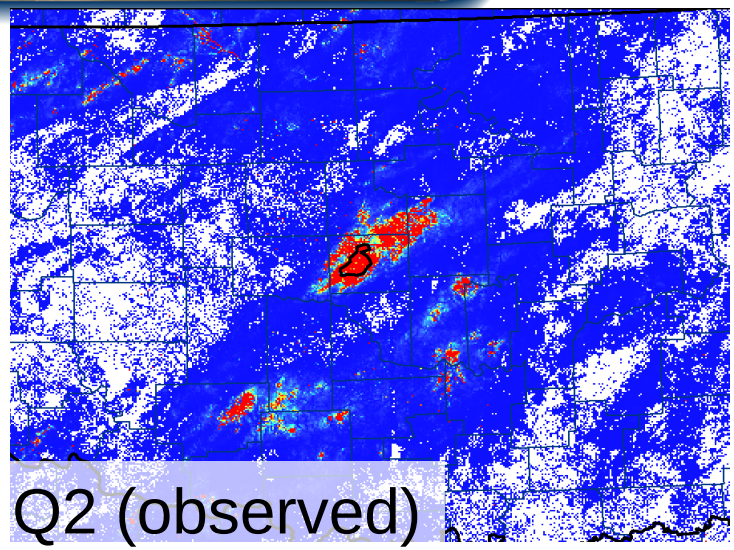


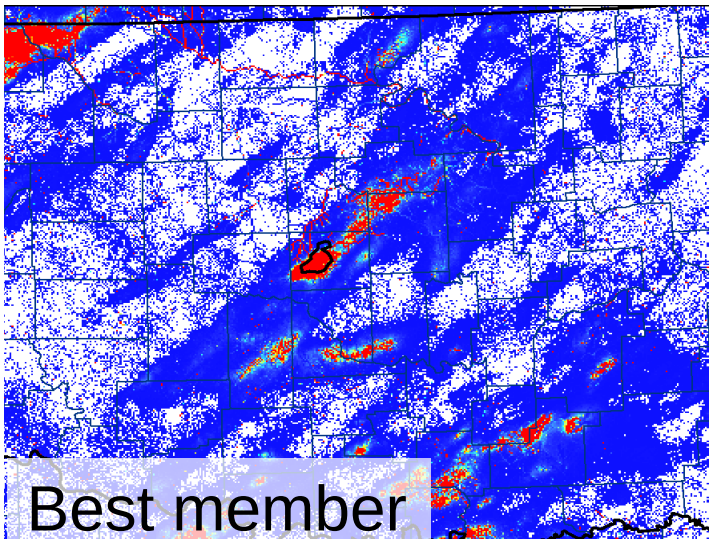
Probabilistic Flash Flood Forecasting using Ensemble Stormscale Precipitation Forecasts

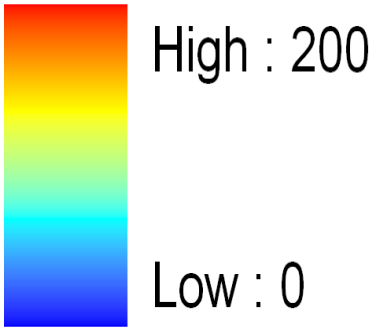
Jill Hardy
Gina Hodges

NSF Graduate Research Fellowship

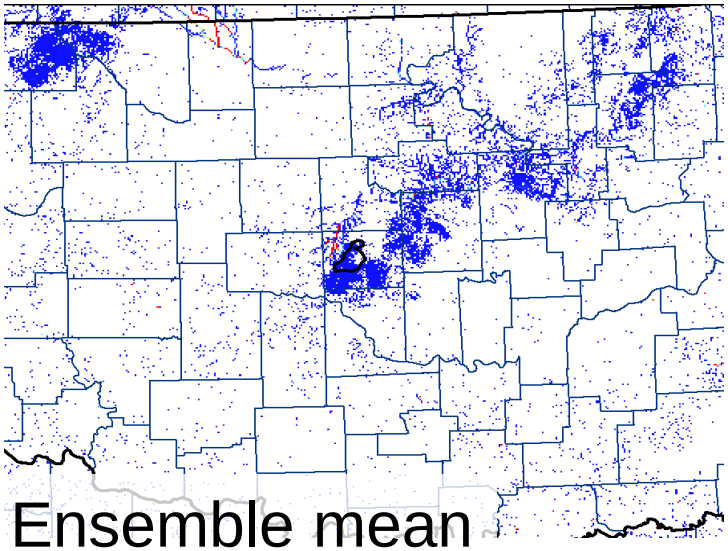
Maximum Return Periods – OKC Flash Flood

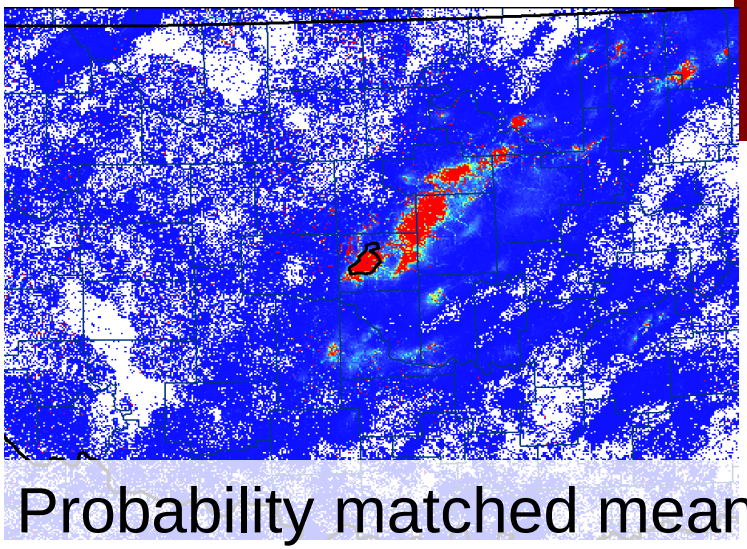






Promising performance from a 12-hr forecast !





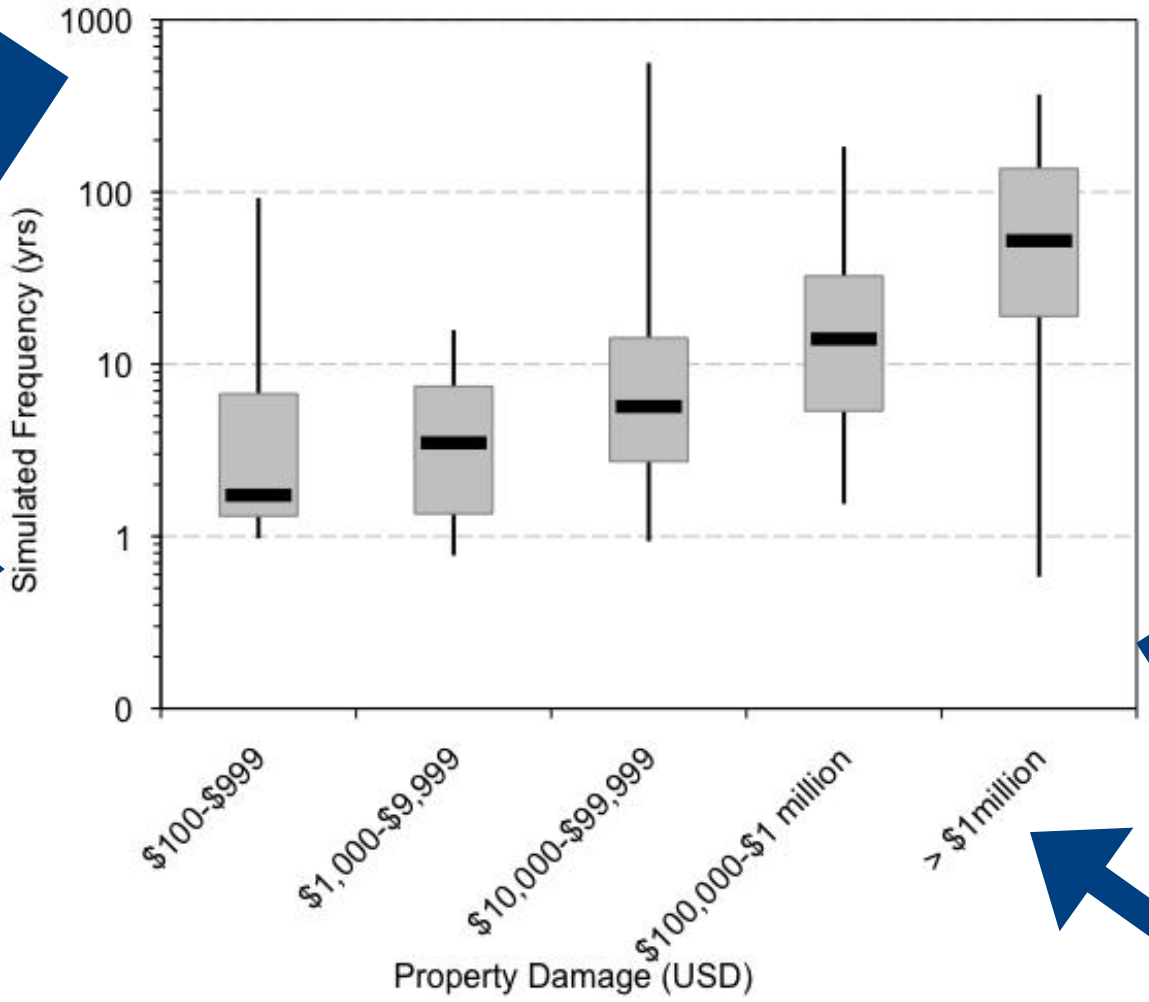
The use of SHAVE and NWS flash flood reports for impact characterization and prediction

Martin Calianno

Laboratoire d'étude des Transferts en Hydrologie et Environnement, Grenoble, France

Are simulations of flash flood severity related to economic impact?

From hydrologic model



From NWS StormDat reports

How does FLASH differ from DHM-TF package?

- Resolution: FLASH runs on back-end of NMQ/Q2 rainfall generation and provides forecasts at the flash flood scale (1 km/5 min presently, with upgrade to 250 m in March vs. 4 km/1 hr)
- Probabilistic instead of deterministic
- Will incorporate GIS exposure factors to yield impact-specific products
- Framework readily accommodates forcing from contemporary QPFs (e.g., stormscale ensembles)
- FLASH is a centerpiece for R&D

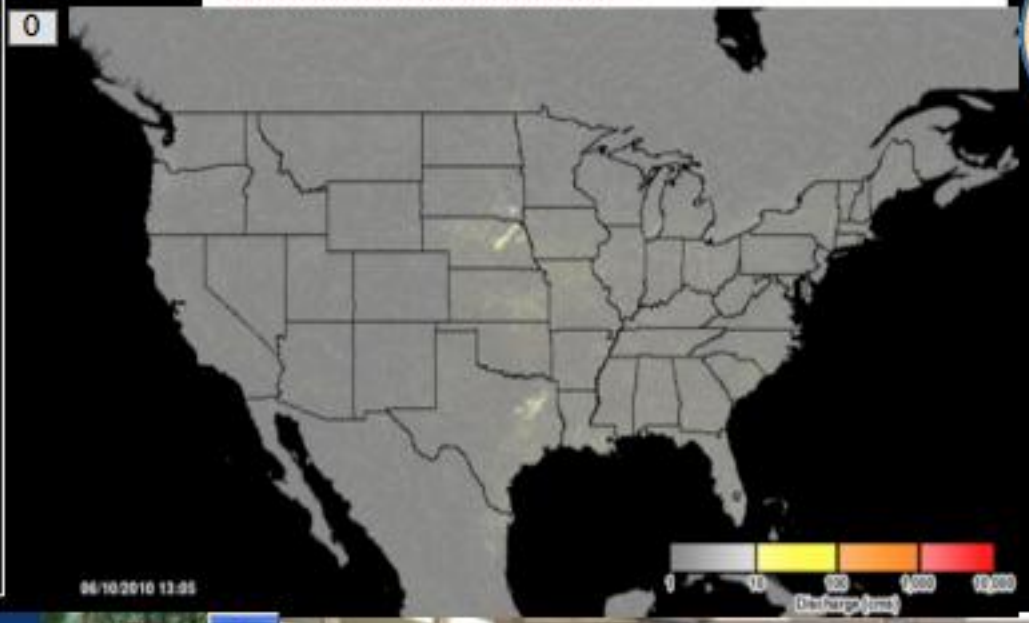
Current Status

- Flash-flood forecasts running at 1 km^2/5 min resolution over CONUS
- Based on single member from CREST model
- Scheduled for testbed implementation in July 2013 at NCEP Hydrometeorological Prediction Center

FLASH

Flooded Locations and Simulated Hydrographs Project

www.nssl.noaa.gov/projects/flash



Relevant Literature

- Calianno, M., I. Ruin, and J. J. Gourley, 2013: Supplementing flash flood reports with impact classifications, *J. Hydrol.*, **477,** 1-16. doi:10.1016/j.jhydrol.2012.09.036
- Gourley, J. J., Y. Hong, Z. L. Flamig, A. Arthur, R. A. Clark, M. Calianno, I. Ruin, T. Ortel, M. E. Wieczorek, E. Clark, P.-E. Kirstetter, and W. F. Krajewski, 2013: A unified flash flood database over the US., *Bull. Amer. Meteor. Soc.,* (in press)
- Clark, R. A., J. J. Gourley, Z. L. Flamig, Y. Hong, and E. Clark, 2013: CONUS-wide evaluation of National Weather Service flash flood guidance products, *Wea. Forecasting* (in review).
- Gourley, J. J., J. M. Erlingis, Y. Hong, and E. Wells, 2012: Evaluation of tools used for monitoring and forecasting flash floods in the United States. *Wea. Forecasting*, **27,** 158-173, doi: 10.1175/WAF-D-10-05043.1.
- Gourley, J. J., Z. L. Flamig, Y. Hong, and K. W. Howard, 2012: On the accuracy of the past, present, and future tools for flash flood prediction in the USA. *IAHS Publ. 351*, ISBN 978-1-907161-26-1, 435-440.
- Wang, J., Y. Hong, L. Li, J. J. Gourley, S. I. Khan, K. K. Yilmaz, R. F. Adler, F. S. Policelli, S. Habib, D. Irwin, A. S. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrol. Sci. Journal,* **56,** 84-98, doi: 10.1080/02626667.2010.543087.
- Gourley, J. J., J. M. Erlingis, T. M. Smith, K. L. Ortega, and Y. Hong, 2010: Remote collection and analysis of witness reports on flash floods. *J. Hydrol.,* **394,** 53-62, doi: 10.1016/j.jhydrol.2010.05.
- Ortega, K.L., T.M. Smith, K.L. Manross, K.A. Scharfenberg, A. Witt, A.G. Kolodziej, and J.J. Gourley, 2009: The severe hazards analysis and verification experiment. *Bull. Amer. Meteor. Soc.*, **90,** 1519-1530.